ALUMINIUM INDUSTRY SUPPLEMENT. A PRACTICAL REVIEW.

METALLURGIA

THE BRITISH JOURNAL OF METALS

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METALLURGIA

The British Journal of Metals
(INCORPORATING THE METALLURGICAL ENGINEER.)

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Improved Facilities for the Manufacture of Heat Treatment Equipment

Wild-Barfield's New Works and Offices

Quantity, diversity of type and size, and the growth in demand for electric furnaces led to congestion in the Holloway works of this company, and new works have been erected which are adequately equipped and staffed and now in production. Brief particulars of these new works are given and attention directed to the facilities provided for the investigation of customers' samples.

CHANGING or controlling the structure of metals and alloys by various methods of heating and cooling is an operation which has become increasingly associated with metallurgical developments. The process is known as heat-treatment, and upon its successful performance depends many modern advances. The ever-increasing demands of the engineer for metals and alloys possessing improved properties would in many cases be impossible of accomplishment without the application of suitable heat-treatment. The success of the many complex alloys developed in recent years for specific purposes is governed largely by the heat-treatment to which they are subjected to develop the properties desired for a particular service. Thus, it can be said that with increasing metallurgical knowledge, its application in practice has necessitated improved means for efficient heat-treatment operations, and the design and construction of furnaces for this work now demands considerable technical and scientific knowledge.

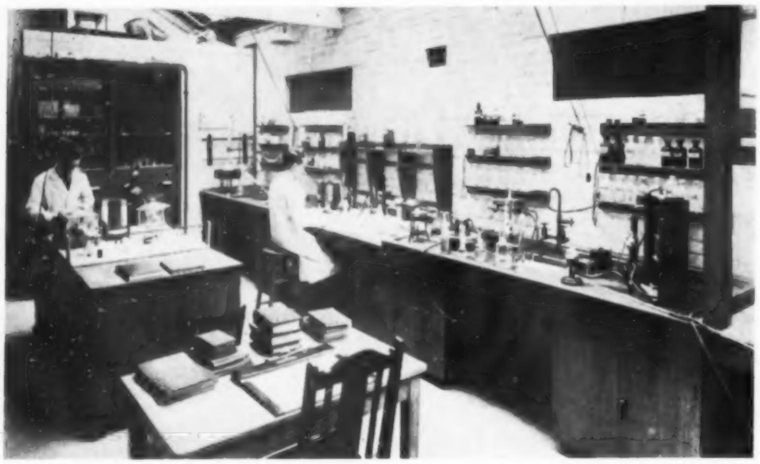
The efficiency with which heating, cooling and handling operations of components can be effected, so that the materials of which they are composed possess the desired service properties, depends upon the equipment and the skill of the operator. It is possible to obtain satisfactorily heat-treated products from an old type inefficient furnace, just as it is possible to produce faulty work in a modern furnace, but improvements in design and operation of heat-treatment furnaces have reduced the possibility of producing inferior work and have resulted in great advances in uniformity in quality of the finished product. The wide range of materials now used, their more complex composition, and the growing variety of service conditions, have reduced the degree of tolerance in the properties of metals and alloys which has increased the need for accuracy and for control of heat-treatment operations.

To-day the underlying principles of heat-treatment operations are better understood and more consideration is given to the many factors which control them. The employment of efficient equipment is more general, and its design and construction has reached what can be regarded as a precision standard. Heat-treatment furnaces are now more generally designed and constructed by specialists whose works are specially laid out to cope with the problems associated with heat-treatment operations, so that the furnaces built are efficient when used to produce the properties in the particular material for which they are designed. The new works and offices of Wild-Barfield Electric Furnaces, Ltd., is an example of progressive works of this type, and some references to them will be of interest.

The facilities afforded at the Holloway works of this company proved inadequate. In quantity, diversity of type and in size, the growth in demand for electric furnaces led to congestion with its consequent difficulties, and in 1938 steps were taken to prepare for the erection of new works. Plans were prepared at once and major contracts placed within a few weeks, so that no time would be lost in coping with increasing demands. The works and offices are now erected, and the change over from the Holloway works to the new works has been effected with the minimum of trouble.

The plans for offices and works were prepared with future extensions in view, the office block, for instance, being arranged so that finally a well-balanced building will extend the width of the frontage. Only two main erection bays have so far been constructed, but the designs permit of large extensions. It should be borne in mind, however, that these works are built mainly for the manufacture of relatively small furnaces, all the larger mechanically operated furnaces being designed and installed by an associated company, Messrs. G. W. B. Electric Furnaces,

View of one of the furnace erection bays.



Part of the chemical laboratory.

Ltd., for whom Wild-Barfield Electric Furnaces, Ltd., manufacture the heating elements and other electrical details.

The office block is a two-storey brick and reinforced concrete building with direct access to the works. The main entrance is at one end of the block, and arranged so that after final extension to the offices it will be centrally situated. Each floor has a central corridor with the individual offices opening on it. The ground floor comprises drawing office, general office, and staffs connected directly with the works and production. The second floor accommodates sales, accounts and executive offices.

The main works bays are each 40 ft. in width, 27 ft. high to the eaves, and are designed to take 10-ton travelling cranes. The buildings are of steel frame construction with brick walls. One of the bays is fitted with roller shutter doors at the front and rear. At the front end of this bay is situated the dispatch department, and it is noteworthy that adequate lifting and handling facilities now provided enable furnaces to be erected and transported complete. The second bay is generally similar, extending to the same depth as the first bay, but adjoins the laboratory buildings behind the office block.

Machine tools do not figure very prominently in electric furnace manufacture, but the lathes, shapers, drillers, grinders, etc., are of modern type and have individual drives. Rolls for plate and angles, shearing and guillotine machines, both electrically and hand-operated, are also installed. Welding equipment is used extensively, both oxygen-acetylene and electric welding being employed. The latter includes spot-welding and arc-welding, and several machines are maintained in fairly constant use. Other items of equipment include paint spraying, which is carried out in an enclosed compartment, and the usual bench and portable tools, for which low voltage plug points are provided throughout the shops.

At the front of the first bay, a test department is well equipped, and is grouped with the main distribution panels. The electric supply is taken from the local Corporation mains at 415 volts 3 phase 50 cycles, this supply feeding all the main plant. The test bay has a 3-phase transformer, 150 kva. capacity, to give voltages from 20 to 600, a Scott-connected group to give a 2-phase output, at a variety of voltages, and a 50 kva. single-phase transformer. These various transformers have the tappings brought to terminals on test panels, with ammeters and voltmeters of various ranges. The 110-volt tapping on the 3-phase transformer is also used to supply the portable drills, etc., which, although single-phase, are balanced as much as possible on the 3-phase mains. Similarly, the lighting is arranged to give as near as possible a balanced load.

The laboratory department, which comprises a chemical laboratory where facilities are afforded for making a complete analysis of any sample submitted, and the metallurgical laboratory, where samples are examined and tests made, is a single storey building. The chemical section accommodates a brick-built storeroom and has titration benches arranged the whole length on one side and furnace bench along the other. The analytical bench is of a very modern type, is adequately fitted, and part of it is allocated to volumetric analysis. The metallurgical section is also well equipped and contains one of the latest types of Vickers pyramid hardness testing machines, complete with the latest improvements; equipment is also installed for carrying out tensile and impact testing. This section also houses the dark room for photo-micrography and spectroscopic analysis. It is equipped with all the necessary apparatus for these processes and comprises a Vickers' projection microscope of the latest type, complete with a full range of objectives, eye-pieces, etc., required for both micro and macro work as well as the necessary equipment for using polarised light. With this equipment magnifications of from 3 to 4,000 are available. The spectroscope installed is invaluable for determining the components of an unknown alloy and an approximation of the content of each element present; the information gained greatly facilitates the chemical analysis of a particular sample.

Adjacent to the laboratory is the heat-treatment shop. Many of the furnaces have been removed to fulfil the urgent demand for plant, but those remaining are sufficient for small-scale experimental work, and additions are being made as circumstances permit. Adequate lifting and quenching facilities are available, together with equipment for the production of protective atmospheres. High- and low-pressure air lines are fitted here, and in the laboratory building, and the electric supply is arranged to provide means for the fluctuating demands likely to be met.

The whole works, the building of which has been carried out under the supervision of Mr. J. P. Coleman, the works' director, is admirably arranged, and is well equipped not only to construct the various types of heat-treatment furnaces in which this firm specialises, but to carry out thorough investigations to determine the most suitable heat-treatment of customers' samples, or in collaboration with customers' own laboratories, technical staffs or advisers.

The laboratory is under the direction of Dr. F. W. Haywood, who has developed a system which enables a regulation heat-treatment record and test sheet to be issued to customers, giving full particulars of the heat-treatment carried out and the results obtained from their own samples.

New Metallurgical Institute

The design for a new Institute of Metallurgy of the Academy of Sciences of the U.S.S.R. has been completed and approved. The building will have four stories, with an aggregate useful floor area of 75,400 sq. ft. It will comprise several groups of laboratories, including a physico-chemical group, in which will be studied the theoretical principles of metallurgical processes; a physico-technical group, where will be studied the properties of metals and research conducted for new alloys. Provision is made for a group of laboratories for technical processes in the metallurgy of ferrous and non-ferrous metals, including one for dealing with refractory materials. A blast-furnace and also an open-hearth furnace will be installed for experimental purposes. The new building to be erected will be adjacent to the present Chemical Institute of the Academy of Sciences.

The Influence of Turbulence upon the Structure and Properties of Steel Ingots

The results of experiments on seven steel ingots are described and their macrostructure, chemical segregation and mechanical properties have been studied. The differences in the structures of the steel ingots are discussed from the point of view of the influence of turbulence, and theories of the mechanism of the solidification of steel are put forward.

IN the preparation of an ingot or casting of any metallic alloy, variations in the casting technique may lead to wide variations in the crystal structure. In steel ingot manufacture, the factors in the actual filling of the mould to which most attention has been paid—apart from questions affecting the composition or degree of killing of the liquid steel—have been the casting temperature, the speed of casting, and the shape and size of the ingot.

Experience in the casting of other metals in addition to steel has shown that another factor—namely, turbulence—may exert a pronounced effect on both the structure and properties. When discussing the solidification of a metal, it is customary to consider first of all a mould filled with liquid metal at rest; such a state of affairs rarely occurs, however, and probably not at all in the normal method of steel-ingot manufacture. Descriptions have been published from time to time of steel ingots cast by somewhat unorthodox methods, in which the turbulent conditions were likely to differ from those existing in normal casting practice, and certain features in the structure of these and of ordinary steel ingots have been explained as being due to the turbulence of the liquid metal in the mould, but knowledge of the actual conditions of turbulence and of the influence of this factor is extremely limited. It was, therefore, considered desirable to investigate the problem. This has now been done by preparing a series of otherwise strictly comparable ingots in which the only variable was the method of filling the mould. The influence of thus changing the conditions of turbulence was determined by examining the structure and properties of the ingots so prepared. The results of this examination are described in Section I in a paper by Dr. L. Northcott.* The paper also contains, in Section II, a description of a series of small composite alloy ingots cast under conditions simulating those of the large steel ingots and prepared in order to obtain information on the influence of the casting conditions upon turbulence. Finally, Section III is composed of a critical discussion of the experimental results, and arguments are advanced to explain certain of the effects observed.

Seven 15 cwt. steel ingots were cast by different methods which were selected as offering different conditions of turbulence of the molten metal in the mould. The methods employed involved: (1) Bottom casting; (2) top-casting, a single stream down the centre of the mould; (3) the use of a multi-hole tundish; (4) a sand mould with a single stream; (5) a single stream near one side of the mould; (6) top-casting with a single stream, stirring with a poker after casting; and (7) casting in a sloping mould. All the ingots were cast from the same melt into moulds of the same shape and size, and the casting temperature and speed of pouring were constant. A separate tundish for each ingot ensured a constant head of metal; all the ingots were top-poured except the first, and six of them were cast in ordinary cast-iron moulds and one into a sand mould.

Method of Sectioning

After comparing the surface quality of the different ingots, the feeder heads were cut off and then an axial slice, 1 in. thick, was sawn off and the axial face ground and polished. A sulphur print was obtained and the axial face then etched to reveal the macrostructure. Using a drill $\frac{3}{4}$ in. in diameter, samples for chemical analysis were taken at the positions adopted by the Committee on the Heterogeneity of Steel Ingots† for determining heterogeneity. Transverse bars, 1 in. deep and the full width of the ingot, were cut at distances of 6 in., 2 ft., and 3 ft. 6 in. from the base to enable more detailed examination to be made of material representing the lower, middle and upper part of each ingot. Tensile test-pieces were machined from a position just below the A and F analysis positions, with the axis of the test pieces parallel with the length of the ingot, and others at right angles from just above the A and F positions. Information on the sulphur distribution, macrostructure, microstructure, chemical segregation and mechanical properties was thus obtained from the 1 in. thick axial slice of each ingot. As will be described later, additional samples were obtained from certain of the ingots for a more complete examination to be made.

A study of the surface quality revealed no great differences as between the different chill-cast ingots, but the ingot cast in the sand mould showed several patches of roughness with a shallow type of undercutting cavity; it possessed the poorest surfaces of all. The macrostructure of each ingot was studied in turn, and two features affected by the casting conditions were the size and the orientation of the columnar crystals. Measurements of the lengths of these crystals on both sides of the axial face were obtained at 6 in. intervals from the base of the ingot are given in a table. A further study of the macrostructure was carried out on the 1 in. bars cut from the axial slices, across the whole width of the ingot.

Micro-examination showed fairly close correlation between the ferrite-pearlite structure and the primary structure in all the ingots, and only a few representative structures are described. Determination of inherent grain size shown by the McQuaid-Ehn test were made on samples cut from certain parts of one of the bars from each ingot. The structure of all samples corresponded to a grain size number of 5, although the crystals from the middle of the ingots were less uniform in size than those only $\frac{1}{2}$ in. from the ingot face, the number of grains per square inch divided by 100 being, respectively, 15–20 and 20–24. Tensile tests, the results of which are given in a table, indicate that (1) the optimum properties in both tensile strength and ductility were shown by the samples composed of columnar crystals of the primary structure; (2) the lowest values were obtained with specimens from a position nearest the axis; (3) the ultimate stress values of the sand-cast ingot were 2–5 tons per sq. in. less than those of the other ingots and the ductility was also lower; (4) the properties of the normally cast ingot—top-cast, single stream down centre—compared favourably with those cast by the other methods and were only fractionally below those of the bottom-cast ingot which was the best of all; and (5) the tensile properties of the steel in the as-cast condition were very much less affected by the methods of casting than by the position in the ingot from which the test-piece was obtained.

In view of the discussion which has taken place from time to time as to the relative properties of columnar and equi-axial crystal aggregates in steel ingots, the upper half of

* To be presented at the Annual General Meeting, 1941, of the Iron and Steel Institute. (Advance Copy.) 42 pp.

† *See* Fifth Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1933, *Special Report No.* 4, Fig. 2, p. 25.

the tilted ingot, which was composed of columnar crystals on one side and equi-axial on the opposite side, was submitted to a detailed examination. The author states that there is, in general, a greater uniformity in the properties of the columnar-crystal samples than of the equi-axial ones in both the as-cast and annealed state, the properties of the equi-axial crystal samples being slightly superior near the edge of the ingot, but falling off more rapidly as the centre is approached. It is noteworthy that hardness determinations on bars from the tilted ingot composed of columnar and equi-axial primary crystals in the as-cast condition and after several heat-treatments showed no significant differences in hardness between the two structures.

Examination for heterogeneity was made by the chemical analysis of samples taken from seven standard positions in each of the ingots. The results are tabulated. The different elements are not distributed identically in the different ingots, but the carbon figures show the general trend of the segregation. In view of the difficulties in sampling there can be little doubt that the true composition differences are actually greater than those indicated in the table, but the figures suffice to show the direction of the changes in chemical composition.

Further information on the influence of the casting method upon turbulence was obtained from a number of small composite non-ferrous alloy ingots, in the preparation of which a red alloy was poured first and was immediately followed by a white alloy of similar density and melting point. Knowledge of the distribution of the stream in the mould was then obtained by examining the distribution of the differently coloured alloys in the ingot.

Assessment of Degree of Turbulence

It is evident from the examination of the 15 cwt. steel ingots and of the 13 lb. non-ferrous alloy ingots that the different casting conditions have exerted a pronounced influence on the ingot structure, and, excluding for the time being the sand-cast ingot, this effect is due solely to the alteration in the conditions of turbulence in the mould brought about by varying the method of pouring.

From the data on the lengths of columnar crystals given there is reason to believe that the processes involving the least turbulence are those requiring the use of the multi-hole tundish or bottom-casting, since long columnar crystals are found in ingots prepared under either of these conditions. Much shorter crystals are found in the last three ingots, stream down one side, poker-stirred and tilted mould, and it is to be expected that, with the exception of the last ingot, turbulence would be most pronounced in these ingots. The "single stream down centre" ingot, cast under conditions more representative of standard practice, is intermediate in columnar crystal size between the two main groups. In the ingot cast in the tilted mould, the continuous flow of metal down the lower face constitutes the most pronounced form of turbulence at or near a mould face and has led to the smallest columnar crystal size. The structure of the metal grown from the opposite face indicates quiescent conditions of growth, and these may be likened to those existing in a bottom-casting using a large slowly running stream. The action of stirring after casting, by maintaining turbulent conditions, has reduced the size of the columnar crystals appreciably as compared with those observed in a similar ingot not stirred. That there is such a large difference in structure between the "stream down one side" ingot and the tilted ingot, which might be thought to have experienced similar turbulent conditions, is presumably due to the partial dissipation of the force of the stream in the latter ingot, owing to the stream striking one of the mould faces. The subsequent wider spread of metal of lower energy is then more readily cushioned by the liquid already in the mould. The much reduced turbulence near the upper face of the tilted ingot has resulted in the growth of long crystals from this face which was farthest from the stream.

The experiments made with the composite alloy ingots, in general, confirm these findings, but a few additional conclusions may be drawn as to the effects of the different casting conditions. For example, it is not possible from an examination of the steel ingots to determine the degree of penetration of the stream into the liquid already in the mould, but this is clearly shown by the composite-ingot method. Its use thus is valuable in demonstrating the comparative absence of major turbulence in the multi-hole-tundish process of casting, and the pronounced penetration of the stream and consequent displacement of the previously poured liquid in the case of ingots cast with a single stream. Furthermore, the reduction of general turbulence by the use of a tilted mould with the single stream is confirmed.

There is one other observation to be made arising from the structure of the tilted mould ingot. The increase in crystal length on the "upper" face as the top of the ingot is approached is clearly due to the reduced turbulence of the liquid in this half of the ingot, together with the smaller temperature increase or the mould face here, since it was in contact for a shorter time with the flow of liquid steel. As the columnar crystals actually reach the *middle* of the ingot at the top, it is evident that under perfectly quiescent or non-turbulent conditions the primary structure of the whole of each ingot would be completely columnar. The difference in turbulence brought about by the different casting conditions has led to the columnar crystals having different lengths, but none of the ingots shows a completely columnar structure. It would appear that the multi-hole-tundish method of casting resulted in the least turbulence of the liquid in the mould, and, although the composite alloy ingot cast by this method shows very large columnar crystals, the steel ingot is by no means completely columnar, and this must be explained as being due to interference from the downward movement of the liquid along the axis of the ingot arising from the feeding of the ingot. The tendency towards completely columnar growth in these particular ingots is therefore insufficient to overcome the disturbing action of this mild flow during feeding.

Arising from the experimental results, the author also discusses the inclination of columnar crystals, Λ-segregates, rate of crystallisation, mechanism of the solidification of steel ingots, banding in the stirred ingot, and presents a summary of his conclusions.

Index to A.S.T.M. Standards, 1940-41

This latest edition of the index of standards issued by the American Society for Testing Materials gives information on 581 standards, which comprise those specifications and method of test that have been formally adopted by the Society, and 371 tentative standards which represent the latest thoughts and practices on the subjects covered; these latter are published as tentative by the Society on the recommendation of the committee concerned, prior to adoption as standard.

This Index covers the 1939 Book of Standards, Parts I, II, and III, together with the 1940 Supplement issued in three parts, which contain all the current standards and tentative standards except the methods of chemical analysis of metal which are published in a special volume. It is not only useful as a reference for the location of a particular standard, but also to anyone wishing to ascertain whether the Society has issued standard specifications, test methods, or definitions covering a particular engineering material or subject.

All items are listed in the index under appropriate key-words, according to the particular subjects they cover. As a convenience, a list is given of the specifications and list in numerical sequence of their serial designations. Copies of this 172-page publication are supplied without charge on written request to A.S.T.M. Headquarters, 260, S. Broad Street, Philadelphia, Pa., U.S.A.

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INCORPORATING "THE METALLURGICAL ENGINEER"

Present and Post-War Industrial Problems

THE magnitude of the nation's task in prosecuting the war to a successful conclusion needs no emphasis, but the importance of making full use of the country's man-power is not always appreciated. At present the nation's war effort must be carried on with growing intensity, and while great progress has been made in arming and equipping the Forces, especially since the withdrawal from France, the need of weapons and materials of war is gradually expanding to support the growing strength of the Forces. However much the United States may assist in giving us "the tools," there must be steady progress in this country to supply the ever-growing need. It must be remembered that in addition to having a much larger armed force, Germany's industrial army far exceeds ours; indeed, if all the man-power of this country were directing its energies to war-work we would still be vastly inferior to Germany in numerical strength. It is probably true, of course, that much of the war-work done in Germany is carried out under duress, and both the quantity and quality of work accomplished may suffer in consequence in comparison with more democratic methods adopted in this country, but the fact remains that we are at a considerable disadvantage numerically.

In addition to the United States, substantial support is being given by Canada, Australia, New Zealand and India in meeting the needs of the Forces, but the products of these countries must be transported, and as shipping is also essential for the transport of raw materials and food to Britain, the maintenance of a continually increasing industrial army in this country is just as essential as an increase in numerical strength of the Forces.

The Government is alive to this fact and has made an appeal for volunteers to undertake engineering work. It is made to all men who have not yet registered for military service and are not in reserved occupations, or who have registered and have been placed in medical categories III and IV, to men who have retired, and to those who are over 16 and under 20 years of age. There is a special need for trained men for such work as shipbuilding and marine engineering, and it is not easy to train men for the majority of operations involved in these industries, but numerous opportunities present themselves in other branches of engineering where special training of a limited character will fit persons to perform essential operations in manufacture, and it is mainly in this direction that the Government has moved. Particulars of new arrangements recently agreed upon between representatives of employers and workers on the question of training volunteers have been issued by the Ministry of Labour and National Service in a supplement to the "Manual on Training for War-Time Work in the Engineering Industry."

It will be appreciated that in modern warfare, in which mechanised units play so important a part, the personnel necessary in the various branches of engineering far exceeds the normal requirements of peace-time activities, and the vital importance of training for the successful development of the country's war-production programme must be emphasised, employers are therefore asked not only to undertake the maximum amount of training required for their own needs, but, as far as possible, to train recruits, in excess of their own needs, on behalf of the Ministry. A large number of recruits to this industrial army is now undergoing training, but a continual flow of volunteers is needed to be steadily absorbed by the industry as soon as they reach the required standard of efficiency.

It is noteworthy that there has been some improvement of late in the supply of raw materials to meet the increasing demand for arms and equipment; this applies to both ferrous and non-ferrous materials, though market conditions still confine the business to narrow limits. The exceptionally heavy aggregate tonnage output of iron and steel as well as the large and increasing import of United States products are almost absorbed by running contracts that extend over the next few months. Control of distribution continues to be necessary to ensure regular adequate supplies to firms directly engaged on work of national importance, but deliveries are on an appreciably increased scale. In view of the difficulties experienced, it is gratifying that at present there is an abundance of raw materials and of semi-finished products which indicates a change for the better. The restriction on the use of steel is still severe, but there is no lack of material for essential requirements.

While the immediate problems of production, involving man-power and materials, arising from present conditions must be given prior consideration, it is gratifying to note that the Government has appointed Mr. Arthur Greenwood to study long-range problems of reconstruction. Machinery has been set up to deal with post-war problems. The object is to plan for the speedy, orderly, co-ordinated change-over of industry and the transfer of our resources from war production to the restoration and reconstruction of our civil life, for the demobilisation of armed Forces and Civil Defence Services, their absorption into employment and the re-settlement of the civil population. The appointment is unusual and is probably the first of its kind by any country at war, and yet the preparation for peace-time activities is surely just as important as preparations for war. The Government is to be congratulated on its foresight, and it is hoped that representative organisations of all kinds and people of knowledge and experience will contribute in a mighty effort to reap the harvest of the country's sacrifices.

The conversion of war-time economy to peace-time economy is also a task of great magnitude. Prolonged and careful study of the subject may well result in the discovery and development of new processes and new products that would absorb newly trained labour when peace is restored. We can be certain that changes will greatly affect each section of industry, and while these cannot be foreseen we can take a lead from past experiences with a view to preparing for the future.

In this issue, for instance, we give particular attention to future trends in the aluminium industry. Geologists tell us that this metal constitutes approximately 8% of the surface of the earth, by comparison with about 5% of iron, and less than 0·02% of copper, zinc and lead. Aluminium, although the most abundant of all metals found in the earth's crust, remained hidden when metals less abundant were in commercial use because of the affinity of the metal for other elements with which it is chemically combined. At present the ores used for producing aluminium economically are strictly limited, but new reduction processes would open up new avenues of usefulness for this metal.

Export Trade Problems

WITH the object of getting to the root cause of existing difficulties in connection with British export trade, the Institute of Export has sent a letter and questionaire to its members. The Council considered that they could not ignore, in the present national need, the very serious obstacles confronting the export trade. The impression seems to be that the problems are caused by material controls, licensing departments, inland transport, and shipping difficulties and censorship delays to cables and mails.

Members are asked to state where they experience their most serious difficulties, what assistance they have been afforded by the various official bodies dealing with export, and whether in their opinion adequate liaison exists between all official bodies. In view of the formation of the Export Council, composed of well-known business men to advise the Government and Commerce on the building up of export trade, members are also asked their opinion on whether there exists an efficient and effective organisation of the export trade through its various channels to produce the results the national programme requires.

After collating members' replies, the Council will compile a reasoned memorandum upon which they will take such steps as are open to them to have the matter raised in suitable quarters.

It is as well that some official action is being taken to inquire into the difficulties many manufacturers are encountering in their efforts to develop the export trade. They realise the paramount needs of war demands, and are aware of the new considerations necessitating the prohibition of exports to certain destinations, but they naturally are anxious to keep open those markets which are included in the Government's policy, and they want the assurance of some reliable authority that delays over the issue of licences, the transport of goods to the various ports and their passage through the Customs will be reduced to a minimum. It is appreciated that the transport of abnormal supplies for war purposes has caused some congestion, but with augmented handling facilities it should be possible to transport materials and manufactures destined for export in a more expeditious manner.

Generally, there can be no doubt that the Government is anxious to cultivate export trade, and has emphasised its importance by expressing the need for concentration upon it where this can be done without endangering our efforts in the war. Manufacturers and the industrial community are aksed to realise that the onus is placed upon them of prosecuting our export trade to the utmost extent. But in many cases the raw materials, upon which manufacturers depend, is conserved for the various war needs, and supplies for these purposes are absorbed so quickly that raw materials for export purposes take a very poor second place. Steel production is a case in point. Most sections of this industry are working at full capacity, and production is being augmented by supplies of billets, blooms and bars from the United States. Shipbuilding, engineering and structural war requirements absorb large quantities of steel, and there is no likelihood of any diminution in its use for these purposes. With increasing imports of this raw material, however, larger releases for export purposes may be confidently expected, and when supplies of greater proportions are released, it would assist manufacturers if deliveries could be speeded up.

The export trade is vital in that it is the means by which we can get foreign exchange to pay for war materials from abroad and for imports of essential food requirements. The Institute of Export, therefore, will have performed a very valuable service if it can effect remedies for the main problems which confront manufacturers, certainly its members should be able to supply all necessary information to permit a competent authority determining the root causes of difficulties which manufacturers and traders for export seem to experience.

Soviet Heavy Machinery Plant Developments

Considerable progress in the Russian heavy machinery industry is contemplated; work is proceeding on designs for thirty-one new heavy machinery plants, and while many are now in course of construction, others will be commenced very shortly. The new plants are being erected in those regions which have practically no heavy machinery building facilities, such as the Urals, Siberia, and Volga regions. These developments have become an economic necessity, largely because the coal industry and the ferrous and non-ferrous metal industries have spread to the eastern regions of the U.S.S.R. during the past few years, and now require the services of a heavy machinery industry to meet their needs. In the near future the Urals, Siberia and the Far East will produce not only metal from the local ores and fuel, but also machinery from the metal. This will obviate transport difficulties to the plants now operating.

Designs are in progress for three large plants for the construction of equipment for the iron and steel, non-ferrous and mining industries, including blast-furnaces, foundry plant, rolling mills, and crushers. One of these plants is now under construction at Krasnoyarsk, Siberia. The construction of a large locomotive works will shortly be commenced in the Kuznetsk Basin, Western Siberia. The plant, which will be situated in the immediate proximity of the railway carriage building works now being erected, is one of the major projects for the industrial development of the Kuznetsk Basin. Thus, Kuznetsk ore and fuel available will be applied to the building of locomotives and railway carriages.

Rapid expansion is taking place in facilities for the manufacture of machine tools. At present designs are being prepared for additions to the plants already in operation at Kiev, Gorky and other towns, as well as designs for nine new plants to be built in Novosibirsk, Ulganovsk, Saratov, Sverdlovsk, Voronezh, and other cities. The new plants are to be erected for the manufacture of grinders, gear-cutting machines, horizontal and vertical borers and other machine tools. Designs are also proceeding for new works for the manufacture of instruments and for the reconstruction of two old works of this type. Work is also in progress on new chemical plant works, and on works for the construction of Diesel engines for the shipbuilding industry.

Forthcoming Meetings

THE INSTITUTE OF METALS.

Birmingham Section.

Feb. 18. "Metals and Foodstuffs," by L. H. Lampitt, D.Sc.

Manchester Metallurgical Society.

Mar. 5. "Gas Heating in Connection with Metallurgy," by C. M. Walter, D.Sc.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

Feb. 28. "Preliminary Calculations in Ship Design," by E. E. Bustard.

Mar. 14. "Pressure Charging of Two-stroke Engines," by J. Calderwood, M.Sc.

THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

Mar. 11. "Wartime Building," by R. Fitzmaurice, B.Sc.

INSTITUTE OF BRITISH FOUNDRYMEN.

East Midlands Branch.

Feb. 22. "Permanent Moulds and Their Application in the Production of Non-ferrous Alloys," by F. Hudson.

Scottish Branch.

Mar. 8. Annual Business Meeting, after which a paper will be read by Dr. J. W. Donaldson.

Falkirk Section.

Feb. 28. "Randupson Process from a Practical Moulding Viewpoint," by — Parker.

West Riding of Yorkshire Branch.

Mar. 8. "Non-ferrous Practice with Special Reference to Light Alloys," by N. C. Ashton.

Recent Investigations of the Dry Cyaniding Process

By D. W. Rudorff, A.M.I.E.E., F.Inst.F.

Research work on the combined employment of gas carburising and nitriding is reviewed. The effects of dry cyaniding on several steels have been studied by means of hardness tests, microstructure investigation, X-ray and chemical analysis; the influence of different carburising gases were also investigated, and the results of a number of tests are given, together with a comparison of results obtained at different temperatures.

AMONG the various new processes developed in recent years for the hard-surfacing of steel, dry cyaniding occupies an important place. This process was originally developed in the laboratories of the Surface Combustion Engineering Corporation, U.S.A., and was initially described by R. Cowan and J. Bryce.[1] It is characterised by the combined employment of gas carburising and nitriding. The term "Nitrocementation," used by Russian metallurgists, appears therefore to be well coined. Nitrocementation is the subject matter of two recent reports which may be said to represent noteworthy contributions to the sparse amount of literature existing on this important subject.

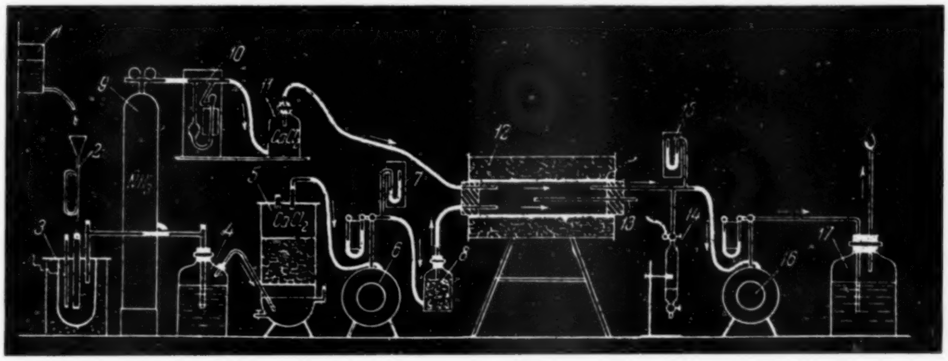


Fig. 1.—Laboratory installation for dry cyaniding.

The experimental work undertaken by N. F. Vjasnikov and A. A. Jurgenson[2] was carried out in the laboratory of the automobile factory, "Stalin." The equipment used for the dry cyaniding of the steels investigated is diagrammatically shown in Fig. 1. Here it is seen that the kerosene contained in the storage container (1) discharges drops of kerosene into the coiled tube (2), from whence the kerosene passes by gravity into the electrically heated vertical retort (3), which is equipped with a connection for the discharge of the carburising gas generated. This retort has an interior diameter of 220 mm. and a height of 350 mm. In addition to the gas-discharge connection, the retort is provided with an opening for the thermocouple, and with a connection for the admission of water or air. The coiled shape of the supply tube (2) serves as a seal to prevent the escape of carburising gas. In order to clean the gas from tar and moisture a cleaner (4), filled with hydrochloric acid, and a scrubber (5), filled at the bottom with the same substance, are provided. In the scrubber (5) the rising gas is further cleaned in a layer of wood shavings followed by a layer of calcium chloride serving as a drying agent.

The amount of dried and cleaned gas discharged from the scrubber is measured by the gas meter 6 and the gauge 7. The gas is then once more dried in the filter 8, and finally enters the retort 12. The ammonia gas, supplied from the steel container 9, passes through a flow meter 10 and a dryer 11 in succession, and is likewise discharged into the retort 12. An alternative arrangement (not indicated in Fig. 1), permitting mixing of the gases prior to their discharge into the retort 12, is also provided. The furnace 12, 75 mm. in diameter and 600 mm. in length, is heated by an electric heating coil, of the nichrome type. The muffle is also made of nichrome, it is 66 mm. in diameter and 600 mm. in length. The muffle is hermetically sealed by two stoppers of iron, the one at the right-hand side accommodating the thermocouple 13, of the platinum-platinum-rhodium type, in addition to the discharge connection through which the rejected gas is passed on to the usual equipment 14, 15, 16 for ascertaining the degree of dissociation of the ammonia, as well as the waste-gas pressure and quantity. Finally, the waste gas is bubbled through water 17 and burned.

The composition of the four types of low-carbon steels investigated is as follows :—

COMPOSITION, HARDNESS AND IMPACT STRENGTH OF THE STEELS INVESTIGATED.

Steel.	C, %.	Mn, %.	P, %.	S, %.	Cr, %.	Mo, %.	N_2, %.	Brinell Hardness.	Impact Strength, Kg. m/cm² (Charpy).
18 XGM	0·2	1·05	0·02	0·02	1·4	0·23	0·009	143	23
1020	0·18	0·55	0·02	0·027	—	—	0·012	126	18
4615	0·16	0·62	0·021	0·018	0·2 *	0·3	0·013	137	24
6115	0·15	0·48	0·021	0·018	0·93†	—	0·01	131	12

* Plus 1·9% Ni. † Plus 0·15% Ni.

The effects of dry cyaniding were studied by means of hardness test, microstructure investigation, and X-ray and chemical analysis. The first point investigated was the influence of the method of gas supply upon the dry-cyaniding process.[3] Three different methods were tried out : (I) Separate admission of carburising gas and ammonia gas to the furnace through individual supply connections (as shown in Fig. 1) ; (II) Joint admission of carburising gas and ammonia gas in mixed state ; (III) Alternating admission of the two gases. In the case of steel 18 XGM, the following three methods were tried out :—

(1) Supplying pre-mixed gas for 90 minutes at a furnace temperature of 830° C.

(2) Admitting carburising gas and ammonia gas separately for 90 minutes at a furnace temperature of 830° C.

1 *Trans. A.S.M.*, 1938, Vol. 26, pp. 766-787.

2 N. F. Vjasnikov and A. A. Jurgenson, "Dry Cyaniding (Nitrocementation)." *Metallurg*, No. 7, 1940 (in Russian).

3 V. E. Prosvirin, *Metallurg*, 1938, No. 11, pp. 82-84 (in Russian). Kantorovich, *Amerikanskaya Technika*, 1938, 5 (in Russian).

(3) First introducing ammonia gas at a furnace temperature of 500° C. (nitriding), subsequently increasing the furnace temperature to 830° C., and then continuing as under (1).

The hardness obtained with these three methods of dry cyaniding was found to be identical; but method (2) proved to yield greatest depth of case. This is due to the fact that in this method the formation of cyanic compounds takes place partly in the immediate vicinity of the surface of the steel, and also, because of its great activity *in statu nascendi*, the cyanide easily diffuses into the steel. If, on the other hand, the gases are pre-mixed outside the furnace, as is done in method II, the amount of active carbon and nitrogen atoms is diminished, and cementation decreases.[4] All tests described in the following were carried out according to method I—that is, with separate admission of carburising gas and ammonia gas.

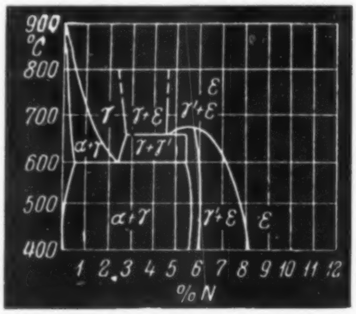


Fig. 2.—Iron-nitrogen constitution diagram.

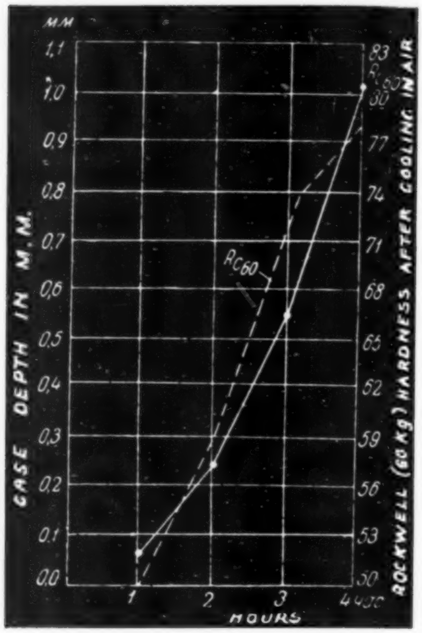


Fig. 3.—Case depth and surface hardness versus length of treatment (Steel 18 × G M)

In order to study the influence of the gas composition upon the process, three different kinds of carburising gas were tried out. These were: (1) gas obtained from kerosene alone, (2) gas obtained from kerosene mixed with water, and (3) gas obtained from kerosene and air. The respective compositions of the carburising gases obtained are given in Table I.

These various gas compositions, with the addition of 30—35% ammonia gas, were tried out for the dry cyaniding of test-pieces of steel 18 XGM, the process temperature and process length being 830° C. and 90 minutes, respectively. Greatest depth of case was obtained with the employment of carburising gas produced from pure kerosene; while with the kerosene-air mixture, only 0·3 mm. case depth was obtained. All tests yielded hardness degrees of 82—84 Rockwell C. It may be added that with increasing furnace temperature the percentage of undissociated ammonia gas in the waste gases was found to decrease, while this percentage increases with rising rate of gas supply to the furnace.

The results of a number of tests conducted to ascertain the influence of the process temperature upon the depth of case and upon the case hardness are given in Table II.

TABLE I.
COMPOSITION OF CARBURISING GAS AND RECOMMENDED PERCENTAGE LIMITS OF THE VARIOUS CONSTITUENTS CONTAINED IN CARBURISING GAS AND WASTE GAS.

Temperature in Retort,‡ °C.	Kerosene supply in 60 mins. Cub. cm.	Carbur. Gas Supplied, Litres.	CO_2, %.	CnHm, %.	O_2, %.	CO, %.	H_2 %.	CH_4, %.	C_6H_6, %.	N_2, %.
800	127	105	0·1	11·1	0·6	1·2	39·1	38·2	8·7	0·8
900	140*	182	0·2	3·0	0·2	6·0	52·0	29·8	8·5	—
760	150†	—	0·2	10·2	0·6	7·0	18·0	—	—	—

Recommended Percentage Limits.	CO_2, %.	CnHm, %.	O_2, %.	CO, %.	H_2, %.	CH_4, %.	C_6H_6, %.	N_2, %.
Carburised gas	<0·2	5—10	0·2—0·6	0·5—1·5	30—40	25—40	5—10	<3·0
Waste gas	<0·3	<2·0	<0·6	<30	55—70	15—20	5·0	10‡—10

* Plus 30 cub. cm. water. † Plus 63 litres air. ‡ Plus 4·5—5·0% NH_3.

It was shown by X-ray analysis that in the surface of the case ε or γ^1 iron, that is, Fe_2N or Fe_4N (see the iron-nitrogen constitution diagram given in Fig. 2) is always present, the actual amounts decreasing with increased process temperature. The X-ray analysis of a hardened test-piece of steel 18 XGM (treated at 600° C.) revealed the presence of ε and γ^1 phase in the surface and to a depth of 0·02 mm.; the surface of the case consisted entirely of nitrides. The case surface was found to be extremely brittle and easily broken by the Rockwell diamond cone (loaded with 60 kilogs.). Test-pieces treated at 700° C. failed to exhibit any brittleness, and X-ray analysis indicated that the ε phase was less, and the γ^1 phase more in evidence. With a dry-cyaniding temperature of 775° C., a zone of gradual transition from the case to the core was noted. At the same time X-ray analysis indicated that only α, γ^1 and γ phase were present in the surface of the case, the ε phase being completely absent. The microstructure of a piece treated at 830° C. exhibited the same character. However, here the case depth was somewhat greater than that obtained with the test-run at 775° C.

A comparison of the results obtained at the different temperatures indicates that in the range of 600—830° C. the total depth of the case, and also its hardness, increase in linear relationship with the process temperature, while the amount of nitrides in the case surface decreases. The composition of the steel is found to be without influence upon the character of the case.

In order to obtain an insight into the distribution of the nitrogen concentration throughout the case depth, surface layers of 0·1—0·2 mm. thickness were removed in succession until a total depth of 1·0 mm. was reached. It was found that nitrogen diffuses into a considerably greater depth than that indicated by microscopic inspection. This fact is evidenced by Table III which shows the nitrogen content at various case depths of the steels investigated.

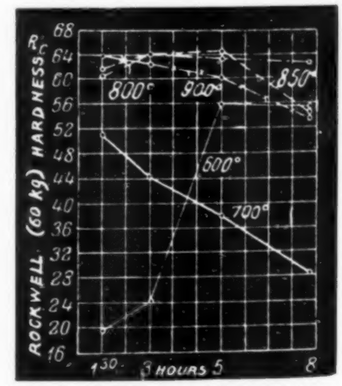


Fig. 4.—Influence of temperature and length of dry cyaniding process upon case hardness (Steel 20 ×)

4 In American practice, continuous muffle furnaces are equipped for the admission of the carburising gas at the charging end, while the ammonia gas is admitted at a point of the furnace where the steel has reached the proper process temperature.—(*The Reviewer.*)

TABLE III.—NITROGEN CONTENT AT VARIOUS DEPTHS OF CASE AS FUNCTION OF TEMPERATURE OF DRY CYANIDING FOR 90 MINUTES.

Steel Brand and Original Nitrogen Content, %.	Temperature of dry Cyaniding.	Case Depth, Mm.	Nitrogen content at various depths of the Case, %. (Distance from Case Surface in mm.) 0·0—0·1	0·1—0·2	0·2—0·3	0·3—0·4	0·4—0·5	0·5—0·6	0·7—0·9
18 XGM $0 \cdot 0093\% N_2$	600	0·05	0·3	0·115	0·03	0·025	0·02	0·015	—
	700	0·17	0·55	0·215	0·07	0·02	0·017	—	—
	775	0·3	0·5	0·26	0·08	0·015	0·013	—	—
	830	0·29	0·5	0·295		0·085	0·055	0·002	0·017
1020 $0 \cdot 012\% N_2$	600	0·06	0·35	0·23	0·13	0·055	0·049	—	—
	700	0·17	0·52		0·22	0·085	0·08	—	—
	775	0·25	0·52	0·16	0·06		0·05	0·03	0·025
	830	0·42	0·415		0·255		0·082	0·02	0·013
4615 $0 \cdot 013\% N_2$	600	0·02	0·32	0·165	0·08	0·05	0·02	0·017	—
	700	0·17	0·36	0·155	0·04	0·035	0·025	—	—
6115 $0 \cdot 01\% N_2$	600	0·02	0·5	0·28	0·06		0·02	0·017	—
	775	0·21	0·47	0·2	0·085	0·06	0·03	0·025	0·019
	830	0·42	0·745		0·3	0·17	0·15	0·013	(at 0·5—0·9 mm.)

are charted in Fig. 3. Here it is seen that in contrast to liquid cyaniding, the case depth increases in linear relationship with the process length. This can be explained by the fact that at temperatures below the Ac_3 point, the diffusing power of the nitrogen is considerably greater than that of carbon. Thus, at the beginning of the treatment, nitrogen enters the surface more easily than carbon, and the surface becomes, therefore, saturated with nitrogen. But this leads in the further course of the treatment to a depression of the critical point Ac_3, and α iron changes into γ iron ; the conditions for the penetration of carbon into the steel are gradually improved and larger amounts of carbon begin to enter into the steel.

Considering, for instance, the case produced with steel 1020 at 775° C. temperature (after 90 minutes of treatment), microscopic measurement yields a depth of case of 0·25—0·4 mm. The table given above, however, indicates a content of nitrogen amounting to 0·025% at 0·8 mm. depth. At this depth the nitrogen content is therefore still twice as large as that of the core. The investigators assert that this fact may serve to explain the great surface hardness of steels showing a very shallow case under the microscope.

Shortly after dry cyaniding has begun, the surface of the piece has become saturated mostly with nitrogen, but notwithstanding the actual depth of case reached, the nitrided layer is too small to be seen in the microscope. The case appears, therefore, smaller than it is in reality. But as treatment is continued, the diffusion of the carbon increases, and it is this increase of the pearlitic case, and not the increase in total case depth, which now becomes visible under the microscope. The investigators state that this conclusion has been confirmed by X-ray analysis and by chemical analysis, and also by the magnitude of the martensitic layer obtained by hardening the piece.

TABLE IV.—INFLUENCE OF PROCESS TEMPERATURE AND LENGTH OF DRY CYANIDING UPON THE CASE HARDNESS (ROCKWELL C).

Steel.	Process Temperature. 600° C. Hours: 1½	600° C. 3	600° C. 5	600° C. 8	700° C. 1½	700° C. 3	700° C. 5	700° C. 8	800° C. 1½	800° C. 3	800° C. 5	800° C. 8	850° C. 1½	850° C. 3	850° C. 5	850° C. 8	900° C. 1½	900° C. 3	900° C. 5	900° C. 8
20	16	21	39	53	24	25	25	24	60	64	64	63	62	62	62	59	64	64	62	54
20 X	18	24	56	54	50	44	38	28	62	63	63	63	62	64	64	54	63	61	60	54
45	28	36	53	56	60	56	53	49	64	63	64	64	62	64	60	60	62	62	62	58
X4 H	27	35	47	54	56	52	43	37	52	53	54	56	56	56	47	47	56	56	56	25

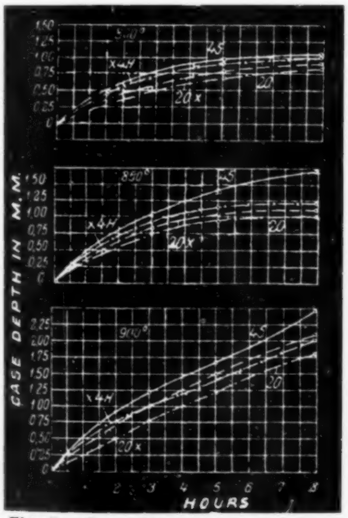


Fig. 5.—Case depth as function of length and temperature of process.

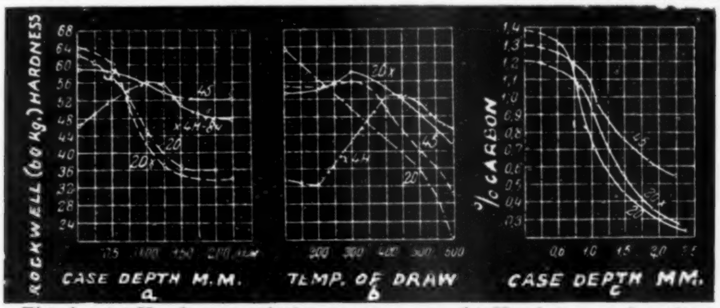


Fig. 6.—(a) Hardness variation across case; (b) Hardness as function of tempering temperature; (c) Variation in carbon content with increasing distance from case surface.

TABLE II.—RELATIONSHIP BETWEEN DEPTH AND HARDNESS OF CASE AND OPERATING TEMPERATURE FOR 90 MINUTES' PROCESS DURATION.

	Process Temperature. 600° C.	700° C.	775° C.	830° C.
Gas supplied in litres	127	135	120	137
Per cent. NH_3 in gas: Supplied	33	33	37	33
Per cent. NH_3 in gas: Discharged	28	15	8	4
Steel 13 XGM: Depth of case, mm.	0·05	0·18	0·42	0·55
Steel 13 XGM: R_C 60: Cooled in air	51	54	56	60
Steel 13 XGM: R_C 60: Quenched in water	62	79	79	82
Steel 1020: Depth of case, mm.	0·06	0·18	0·42	0·52
Steel 1020: R_C 60: Cooled in air	42	46	42	47
Steel 1020: R_C 60: Quenched in water	60	69	79	83
Steel 4615: Depth of case, mm.	0·04	0·18	0·35	0·57
Steel 4615: R_C 60: Cooled in air	50	48	53	58
Steel 4615: R_C 60: Quenched in water	60	70	81	82
Steel 6115: Depth of case, mm.	0·03	0·18	0·35	0·52
Steel 6115: R_C 60: Cooled in air	49	45	44	60
Steel 6115: R_C 60: Quenched in water	62	70	77	83

Another series of tests was carried out in order to ascertain the influence of length of dry cyaniding upon the depth of the case and upon the character of the case produced. The results obtained in the dry cyaniding of steel 18 XGM at 830° C. temperature, and for periods of 1, 2, 3 and 4 hours,

The microstructure of the case produced on a piece of steel 18 XGM by dry cyaniding at 830° C. for 3 hours followed by cooling in air, is said to show three clearly distinguishable zones : (1) a dark surface zone containing α, γ^1 and ϵ phase, (2) a light middle zone composed of martensite containing nitrogen, and (3) a transition zone containing a mixture of martensite and troostite.

The laboratory equipment used by Braun, Vlasov and Goldina[5] is somewhat more elaborate than that shown in Fig. 1, but it is identical in principle. The tests were preceded by a study of various mixtures of carburising gas, and it was decided to conduct all tests with a mixture of 80—75% carburising gas produced from kerosene, and 20—25% ammonia gas.

5 M. P. Braun, A. M. Vlasov and R. M. Goldina, "Nitrocementation of Steel," *Metallurg*, No. 7, 1940 (in Russian).

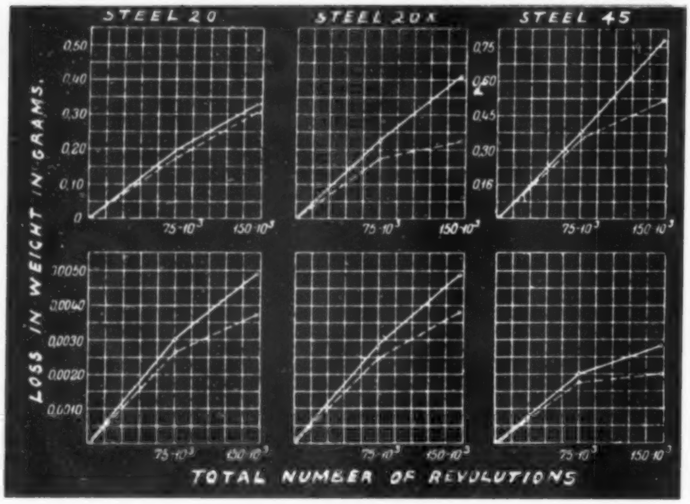


Fig. 7.—Results of wear resistance test (Amsler machine) Top : with sand. Bottom : with oil.

The scope of this investigation extended to a study of dry cyaniding as applied to the various steels listed below :—

Steel No.	C, %.	Cr, %.	Mn, %.	Si, %.	P, %.	S, %.
20	0·2	0·07	0·45	0·22	0·011	0·025
20 X	0·24	0·82	0·42	0·23	0·014	0·024
45	0·44	0·05	0·57	0·23	0·015	0·024
X4H	0·34	1·47*	0·46	0·3	0·015	0·01

* Plus 3·57% Ni.

Various process temperatures, ranging from 600—900° C., were tried out with the process length being varied from 1½—8 hours. It should be noted that the test-pieces from steel X4H were hardened prior to dry cyaniding. The results of the various tests are listed in Table IV.

For steel 20X, a graphic representation of these relationships is shown in Fig. 4. For a constant process temperature of 600° C., a continuous increase in hardness is seen to take place for the first 5 hours; after that, a slight gradual decline in hardness is observed. With a temperature of 700° C., a steady fall in hardness is seen to take place. With 800° and 850° C. process temperature, no great changes in hardness take place during the first 5 hours, while at 900° C. temperature the hardness decreases gradually from the commencement of the treatment.

The graphs reproduced in Fig. 5 show the increase in depth of case with time, and at various temperatures. Steel 45 shows the greatest increase in case depth, and steel 20 the smallest, intermediate values being obtained with the two other steels. At 800° C. the speed of case formation is seen to be rather small. But with 850° C. the speed of case formation is considerably increased, and that of steel 45 becomes greater than that of the others. However, at 900° C. the speed of case formation of steel 45 again approximates that of the other steels.

Particular attention was paid to the investigation of the "white-layer" formation which forms on the surface of the steel during dry cyaniding. This white layer formation was observed to be especially pronounced in the dry cyaniding of the alloy steels X4H and 20 X, on which it was found to appear shortly after commencement of the treatment, and even with low-process temperature. The white layer was also noticed in the nitro-cementation of the carbon steel, but here it formed on a somewhat smaller scale, and only after long treatment at high temperature. In the dry cyaniding of steel X4H, the white layer attained a thickness of 1·0 mm. after 3 to 5 hours of treatment, the layer being penetrated by martensitic needle formation. Extension of the dry-cyaniding process to 8 hours produced a granular appearance of the white layer with chains of small carbides deposited at the grain boundaries. In order to explore the nature of the white layer a study was undertaken of the hardness variation across the depth of the case, while the changes in structure and hardness caused by tempering at various temperatures were also investigated. From the results of these investigations, the conclusion was drawn that the white layer represents austenite alloyed with nitrogen.[6]

The variations in hardness at various case depths, after 5 hours of dry cyaniding at 850° C., are shown in Fig. 6a. It is interesting to note that with steel X4H, the hardness at first increases with the depth until a hardness of 56 Rockwell is reached at 1·25 mm. below the surface. Only from this point on, a decrease in hardness with increasing depth takes place. This rather unique characteristic was found to occur only with this particular steel. The variations in hardness as a function of the temperature of draw, after dry cyaniding for 8 hours at 850° C., are charted in Fig. 6b. Here it is seen that steel 20, which exhibited a very insignificant white layer, showed a continuous fall in hardness with increased temper. Steel 20 X and steel 45 show an actual increase in hardness at 300° C., but after that the hardness decreases with the tempering temperature. With steel X4H, which possessed a very pronounced white layer and low hardness after dry cyaniding, and subsequent quenching in water from 850° C., a sharp increase in hardness was observed after tempering at 400°—500° C.

Fig. 6c illustrates the decrease in carbon content in the case with increasing distance from the surface after dry cyaniding for 5 hours at 850° C. This graph shows that up to a depth of approximately 0·6 mm., the rate of decrease in carbon content with the depth is fairly gradual, while beyond this depth the rate of decrease is much greater.

Steel 20X, subjected to dry cyaniding for 3, 5 and 8 hours at 800° C., exhibited austenitic structure in the surface. After tempering for 2 hours at 500° C., this austenite began to transform into martensite, while, after heat-treating for 2 hours at 300°C., a more coarse martensite with a network of carbides obtained. Tempering for 3 hours at 300° C. disintegrated the austenite into troosto-martensite.

The aforementioned observations confirmed the investigators in their opinion that the white layer consists of austenite. It is stated that by ordinary cementation of the steels 20 and 20 X at 920°—950° C. for 15—18 hours, no austenite can be obtained. It is, therefore, evident that in the dry-cyaniding process the formation of very stable alloys of nitrogen with austenite obtains at temperatures as low as 800°—850° C.

Investigations regarding the wear resistance of dry-cyanided surfaces were carried out by means of an Amsler machine. The wear tests were made with sand and with oil. The results obtained are charted in Fig. 7, where it is seen that in all three steels the loss in weight by wear of the dry-cyanided surface is below that shown for the alternative treatment. It is also seen that the superior resistance to wear of the dry-cyanided pieces becomes particularly pronounced after 75,000 revolutions. The higher wear resistance of the dry-cyanided pieces is ascribed to the presence of a certain amount of austenite present in the surface of the case. The treatment of the three steels referred to in Fig. 7 was as follows : : Steel 20 and steel 20 X, dry cyaniding for 2 hours at 850° C. (dotted lines) versus cementation at 930° C. for 18 hours, with subsequent quenching from 850° C., followed by tempering at 180° C. for 2 hours; steel 45—dry cyaniding as before (dotted lines) versus quenching from 860° C., and drawing at 180° C.

6 Regarding the origin and nature of the white layer, the following literature may be referred to: R. Cowan and J. Bryce, loc. cit.; H. E. Wheeler, "Nitrogen in steel and the erosion of guns," *Trans. A. Inst. Min. and Met. Eng.*, Vol. 68, 1922; W. H. Lester "The white layer in gun tubes and its relation to the case of nitrided chromium-aluminium steels," *A. Soc. Steel Treat.*, Nitriding Symposium, Oct., 1929; W. H. Snair and W. P. Wood, "The white layer structure in the erosion of machine-gun barrels," *Trans. A. Soc. Met.*, Vol. 27, 1939, p. 608-620.—(*The Reviewer.*)

The Effect of Prolonged Heating at 80° C on Copper Wire*

By E. Voce, Ph.D., M.Sc.

Three different brands of electrolytic copper, each in the form of hard-drawn wire of two different diameters, were heated at 80° C for periods up to 18 months. The degree of softening of the wires, determined by tensile tests, was not appreciable with some of the materials, and in no case was it complete. The results show that the softening of hard-drawn high conductivity copper wire on long heating at 80° C. is less than was asserted by von Zeerleder and Bourgeois.[1]

IN the course of a paper upon the "Effect of Temperature Attained in Overhead Transmission Cables," von Zeerleder and Bourgeois,[1] after discussing the heating of overhead transmission lines by solar radiation and the passage of electric current, wrote: "In order . . . to get reliable figures hard-drawn wires of copper, pure aluminium, and Aldrey† were exposed to relatively low temperatures for periods ranging over several months up to one year. It was found that copper and pure aluminium, if kept at 80° C. for 41 days (1,000 hours), were completely annealed, whereas Aldrey was not in the least affected by temperatures up to 100° C., even if applied for one year (8,760 hours). A marked diminution of tensile strength could be observed only at temperatures of 120° C. and over."

No details of the analysis of the copper or pure aluminium used in these experiments were given, nor were any actual test results quoted; it is clear from the last sentence, however, that the tensile test was employed to assess the degree of softening or annealing.

Howell and Paul[2] have referred to the work of von Zeerleder and Bourgeois in connection with aluminium, and have published figures which show that hard-drawn commercial aluminium of 99·21% purity suffered a diminution in tensile strength of only 5% after 652 days at 100° C. Even after 139 days at 150° C. this material, which contained silicon 0·13%, iron 0·53%, copper 0·11%, and manganese 0·02%, was not completely annealed. It has, however, been shown that work-hardened aluminium of purity greater than 99·99% recrystallises and softens at temperatures below 80° C. A number of researches on this point, including those of Calvet[4]; Trillat and Paić[5]; Calvet, Trillat and Paić[6]; and Kratz.[7]

In discussing the paper of von Zeerleder and Bourgeois, Moore described experiments in which high-conductivity copper wires (composition not stated), hard-drawn to No. 16 s.w.g. (0·064 in. diameter) and No. 20 s.w.g. (0·0363 in. diameter), were heated at 96° C. to 100° C. for periods up to 100 days. He gave a series of results, from which the following have been extracted:—

TABLE I.

Duration of Annealing, Days at 96° to 100° C.	Average Tensile Strength, Tons/in.².	
	16 s.w.g.	20 s.w.g.
0	30·2	29·0
42	23·2	24·6
100	18·7	22·1

While these figures certainly show that a considerable degree of softening took place at 96° C. to 100° C., they give no support to the claim that copper is "completely annealed" after 41 days at 80° C., the tensile strength of annealed copper wire being about 15 to 16 tons/in.². Much work has been published‡ upon the annealing of copper, generally concerned with shorter times and higher temperatures. The papers of Webster, Christie and Pratt,[11, 12] of Alkins and Cartwright,[13, 14] of Jareš and Jeníček,[15] and of Rolle and Schleicher[16] are among the more important. The combinations of longest time and lowest temperature used in these investigations were, respectively:—

Webster, Christie and Pratt	1 hr.	at 190° C.
Alkins and Cartwright	24 hrs.	„ 130° C.
Jareš and Jeníček	256 hrs.	„ 175° C.
Rolle and Schleicher	1 hr.	„ 190° C.

As the possibility of softening on heating at relatively low temperatures is important in connection with the use of copper for electrical purposes, an investigation upon

TABLE II.
ANALYSES AND ELECTRICAL CONDUCTIVITIES OF THE COPPERS.

Elements Present.	Composition of Specimens, %.		
	O.F.H.C. Based on Cathode.	O.R.C. Wire-bar.	C.C.C. Wire-bar.
Antimony	0·0001	0·0005	0·0005
Arsenic	—	0·0008	0·0003
Bismuth	—	<0·00005	0·00001
Chlorine	—	—	Trace
Cobalt	—	<0·00005	—
Copper	99·98	99·971	99·961
Iron	0·002	0·0020	0·0023
Lead	0·0005	0·0004	0·0013
Manganese	Trace	Nil	Nil
Molybdenum	—	Nil	<0·0001
Nickel	—	0·0009	Trace
Oxygen	0·0001 (approx.)	0·019	0·030
Selenium	0·0015	0·0009	Trace
Silica (SiO_2)	—	0·0008	(See below)
Silver (+ Gold)	0·0017	0·0010	0·000062
Sulphur	0·0027	0·0009	0·0017
Tellurium	0·0015	0·0006	Nil
Tin	0·001	Nil	0·0006
Zinc	—	<0·0001	Nil
Insoluble in Acid	—	—	0·0030 (0·001 volatile with HF)
ELECTRICAL CONDUCTIVITY, % OF I.E.C. STANDARD FOR ANNEALED COPPER AT 20° C.			
Hard-drawn wires—			
0·160 in. diameter	99·4	100·1	99·7
0·066 in. „	98·6	98·9	99·7
Fully annealed wires—			
0·160 in. diameter	101·6	102·0	102·4
0·066 in. „	100·2	100·7	100·7

° The following specifications are relevant:

B.S. 125, Hard-Drawn Copper Solid and Stranded Circular Conductors for Overhead Power Transmission Purposes.

Diameter 0·162 in.; min. tensile strength 27·4 tons/in.²
„ 0·064 „ „ „ 29·5 „

B.S. 174, Overhead Line-Wire Material (Non-Ferrous) for Telegraph and Telephone Purposes. (H.C. Copper Wires.)

Diameter 0·1582 in.; tensile strength 28·2 tons/in.²
„ 0·0662 „ „ „ 30·5 „

(The tensile strengths for B.S. 174 are calculated from the specified breaking loads.)

* *Jour. Inst. Metals*, Jan., 1941, Part 1, **67**, pp. 1-7.

† Aluminium containing magnesium 0·4%, silicon 0·5—0·6%, and iron less than 0·3%, quenched, cold-drawn and annealed.

‡ References 9 to 16 (inclusive) form a few selected examples.

1 A. von Zeerleder and P. Bourgeois, *J. Inst. Metals*, 1929, **42**, 321-329 (especially bottom of p. 323).
2 F. M. Howell and D. A. Paul, *Metals and Alloys*, 1934, **5**, 176-179.
4 J. Calvet, *Compt. rend.*, 1935, **200**, 66-67; *Metallurgist* (Suppt. to *Engineer*), 1935, **10**, 26-28.
5 J. J. Trillat and M. Paic, *Compt. rend.*, 1935, **200**, 1037-1039.
6 J. Calvet, J. J. Trillat and M. Paic, *Compt. rend.*, 1935, **201**, 426-428.
7 E. Kratz, *Aluminium-Archiv*, 1937 (**6**).
8 W. A. Baker, *J. Inst. Metals*, 1939, **65**, 345-353.
9 J. J. Hoop, *Min. and Met.*, 1935, **16**, 393.
10 N. B. Pilling and G. P. Halliwell, *Proc. Amer. Soc. Test. Mat.*, 1925, **25** (II), 97-119.
11 W. R. Webster, J. L. Christie and R. S. Pratt, *Trans. Amer. Inst. Min. Met. Eng., Inst. Metals Div.*, **1927**, 233-252.
12 W. R. Webster, J. L. Christie and R. S. Pratt, *Trans. Amer. Inst. Min. Met. Eng.*, 1933, **104**, 166-169.
13 W. E. Alkins and W. Cartwright, *J. Inst. Metals*, 1933, **52**, 221-245.
14 W. E. Alkins and W. Cartwright, *J. Inst. Metals*, 1934, **55**, 189-199.
15 V. Jareš and L. Jeníček, *Internat. Assoc. Test. Mat. London Congr.* [*Proc.*], **1937**, 17-20.
16 S. Rolle and H. M. Schleicher, *Metals and Alloys*, 1940, **11**, (3), 82-87.

well-authenticated materials was carried out. A temperature of 80° C. was selected for the tests with the object of providing a direct check upon the statement of von Zeerleder and Bourgeois already quoted.

The following well-known commercial varieties of electrolytic copper were obtained for the tests :—

O.R.C. brand copper, made by the Ontario Refining Co.
C.C.C. brand copper, made by the Chile Copper Co.
O.F.H.C. brand copper, made by the United States Metal Refining Co.

The first two are oxygen-bearing (tough-pitch) coppers, and O.F.H.C. is an oxygen-free high-conductivity copper.

The Ontario Refining Co. (now the Copper Refining Division of the International Nickel Co.) and the Chile Copper Co. each provided a full chemical analysis of a wire-bar cast simultaneously with that supplied for the tests. The United States Metals Refining Co. gave an analysis of the cathode from which their wire-bar had been made, stating that O.F.H.C. wire-bar produced at that time contained 0·002% of iron and less than 0·007% of oxygen, and that otherwise the composition of the wire-bar could be taken as practically the same as that of the cathode. As a check upon this statement, the silver content of the finished product was determined chemically and exactly confirmed. A determination of the oxygen content by the precision method, described by Baker,[8] gave 0·0001% oxygen, which was almost the same as the blank of the apparatus. The analyses are given in Table II, in which electrical conductivities are also included. Spectrographic analyses of the actual wires showed that no important changes of composition took place during their preparation from the wire-bars.

Wires of each material were hard-drawn to 0·160 in. diameter and 0·066 in. diameter by the same manufacturer under carefully controlled conditions designed to impart a tensile strength of as nearly as possible 28·5 tons/in.² to each brand of copper in the thicker wire and 29·5 tons/in.² in the thinner wire.* Short lengths, straightened by hand, were heated at 80° ± 1° C. for periods ranging from 1 month to 18 months, after which tensile tests were carried out at room temperature. The specimens were not under stress during the heating. Tests were also made upon the wires in their original hard-drawn condition, after annealing for 1 hour at 575° C., and after storage for 27 months at ordinary temperature. A gauge-length of 4 in. was used,

TABLE III.
TENSILE TESTS ON HARD-DRAWN COPPER WIRES AFTER PROLONGED HEATING AT 80° C.

Diam. of Wire, In.	Condition.	O.F.H.C. Tensile Strength, Tons/in.².	O.F.H.C. Elongation, % on 4 in.	O.R.C. Tensile Strength, Tons/in.².	O.R.C. Elongation, % on 4 in.	C.C.C. Tensile Strength, Tons/in.².	C.C.C. Elongation, % on 4 in.
0·160	As hard-drawn.	28·7	3	28·4	3	28·8	3
	After						
,,	1 month at 80° C.	28·6	4	27·9	3	27·3	2
,,	3 months ,,	28·8	4	27·4	4	26·5	4
,,	6 ,, ,,	28·5	4	26·9	4	25·5	6
,,	9 ,, ,,	28·8	4	26·4	4	24·0	9
,,	18 ,, ,,	28·9	4	25·2	7	21·9	14
,,	1 hour at 575° C.	15·4	46	15·4	47	15·4	46
,,	27 months at ordinary indoor temp.	29·0	4	28·5	3	28·9	4
0·066	As hard-drawn.	30·2	2	29·3	2	29·7	2
	After						
,,	1 month at 80° C.	29·5	2	27·0	2	26·4	3
,,	3 months ,,	29·1	2	25·4	3	23·5	6
,,	6 ,, ,,	29·5	2	24·6	4	21·9	10
,,	9 ,, ,,	29·5	2	23·8	5	20·5	13
,,	18 ,, ,,	29·7	2	22·5	10	18·9	20
,,	1 hour at 575° C.	15·1	40	15·4	43	15·1	43
,,	27 months at ordinary indoor temp.	30·9	2	30·0	2	29·9	2

Each figure is normally the means of six determinations.

and six specimens of each wire were tested at each stage. Table III records the mean results. In some cases specimens failed to break within the gauge-length, and therefore the elongation values do not always represent the average of the full six tests. Individual test results generally did not vary from the mean values by more than about ± 0·3 tons/in.² and ± 1% on 4 in. for ultimate strength and elongation, respectively, though when appreciable softening had occurred the variation of elongation was somewhat greater.

The results provide conclusive evidence that the softening on prolonged heating at 80° C. of these hard-drawn wires, prepared from electrolytic coppers typical of those in current use, is far less than would be inferred from the statement of von Zeerleder and Bourgeois.

The differences in behaviour of the three coppers are sufficiently striking to deserve mention. In comparing the results, however, it must not be assumed that other wires from these brands of copper will necessarily behave in exactly the same way as those on which these tests were carried out. Although the analysis of each brand of copper has been accepted by the individual manufacturers as typical of their product, small variations in the amount and type of impurities may affect the behaviour of copper wires very considerably. In particular, it should not be assumed that other brands of oxygen-free high-conductivity copper will produce wires having the same characteristics as the O.F.H.C. material tested.

TABLE IV.
PERCENTAGE OF THE ADDITIONAL STRENGTH INITIALLY IMPARTED BY DRAWING REMAINING AFTER 18 MONTHS AT 80° C.

Material.	Remaining Work-hardening, %. 0·160 in. Diam. Wire.	Remaining Work-hardening, %. 0·066 in. Diam. Wire.
O.F.H.C.	98	95
O.R.C.	91	51
C.C.C.	71	26

TABLE V.
HARDNESS TESTS AFTER VARIOUS TREATMENTS ON ⅝-IN. DIAMETER ROD ORIGINALLY COLD-DRAWN TO 50% REDUCTION OF SECTION.

Condition.	O.F.H.C. Hardness, Vickers Pyramid Nos.	O.F.H.C. Work Hardness Retained, %.	O.R.C. Hardness, Vickers Pyramid Nos.	O.R.C. Work Hardness Retained, %.	C.C.C. Hardness, Vickers Pyramid Nos.	C.C.C. Work Hardness Retained, %.
As Cold-Drawn to 50% Reduction.	114	100	116	100	115	100
After 1 hr. at 200° C.	114	100	114	97	113	97
250° C.	114	100	54	18	48	11
300° C.	108	92	46	8	46	8
350° C.	50	14	44	5	44	5
400° C.	47	9	45	6	45	6
500° C.	45	7	44	5	44	5
(Fully annealed) 600° C.	40	0	40	0	40	0
After 24 hrs. at 200° C.	112	96	56	21	48	11
250° C.	112	96	45	6	45	6
300° C.	64	32	44	5	44	5
350° C.	44	5	44	5	43	4
400° C.	43	4	42	3	42	3
After holding at 250° C. for :						
10 minutes	116	100	114	97	113	97
1 hour	114	100	54	18	48	11
5 hours	113	99	46	8	46	8
1 day	112	97	45	6	45	6
5 days	105	88	45	6	44	5
1 month	81	55	44	5	44	5

A useful basis of comparison is provided by calculating the percentage of hardening due to cold work remaining after the full 18 months at 80° C., as assessed by ultimate strength. This percentage, given in Table IV, is expressed by the ratio :

$$\frac{\text{Strength after 18 months at 80° C. } \textit{less} \text{ Annealed Strength}}{\text{Strength as initially hard-drawn } \textit{less} \text{ Annealed Strength}} \times 100.$$

Even after the full 18 months at 80° C. the strength of the O.F.H.C. copper was unimpaired in the thicker, and only slightly reduced in the thinner, more heavily drawn wire. The loss of strength was greater in the C.C.C. than in the O.R.C. Silver is well known to exert a powerful effect in retarding the softening of work-hardened copper, and it is probable that the greater reduction of strength

(Continued on page 128)

ALUMINIUM INDUSTRY

TREND IN MANUFACTURE AND FUTURE APPLICATIONS

February, 1941 METALLURGIA Vol. XXIII, No. 136

Foreword

By Col. W. C. Devereux, F.R.Ae.S.

WHEN the Editor asked me to contribute to this issue, and suggested that I should take as my thesis the factors which should influence the future prosperity of the aluminium industry, I readily accepted an opportunity of setting out my views on this subject.

Of all the many factors affecting the future of the industry after the winning of the war, I consider the most important to be the price of primary aluminium. However efficient our fabricating process, however much technical improvement we are able to effect in the properties and applications of aluminium alloys, the factor which will ultimately decide the extent to which these alloys will be used in the industry will be cost compared with that of other materials. Clearly, we cannot usefully discuss the future extent of the use of aluminium without first attempting to picture the price situation after the war.

Up to the outbreak of war, the aluminium industry enjoyed a certain prosperity owing to the fact that it was a relatively new industry, whose productive capacity was increasing slowly in the wake of increasing demand for its products ; moreover, its output was more or less limited by quotas fixed from year to year by international agreement through the Cartel, which also controlled the price of virgin aluminium in most countries.

The war, however, has upset this safe methodical progress. Aluminium is a vital war material, and therefore all the belligerent countries and their respective friends are desperately striving to increase production at all costs. The position in which this country finds itself to-day with regard to the supply of aluminium is largely a result of too great a dependence on outside supplies of bauxite and aluminium. Perhaps no one could foresee the collapse of France and occupation of Norway, but the fact remains that the loss of those sources of raw material was a very serious blow to our war effort. This dependence on outside sources of supply may also have far-reaching effects after the war if it is allowed to persist.

Plant for the production of aluminium alloys and for the fabrication of light alloy components has been increased many fold since the outbreak of war, while the production in this country of the primary aluminium, upon which the plants depend for raw materials, has failed to keep pace with the increased demand. Consequently, we have been forced to rely to an even greater degree upon supplies from overseas.

We are, therefore, faced with the prospect of having, after the war, a very large and highly organised fabricating industry, lacking adequate domestic sources of its raw materials and thus being unable to have any say in the fixing of their price.

The responsibility for this unhappy state of affairs must be accepted by the aluminium producers of this country, who have shown themselves singularly lacking in vision and have done little to make themselves independent of foreign pressure in the fixing of prices and production quotas. Unless these producers can bring themselves to forget all about the Cartel system and decide to sell aluminium, not at an artificial price fixed by international agreement, but at a price commensurate with the actual costs of production, we shall find ourselves after the war just as dependent upon overseas producers as we ever were.

Research on Domestic Ores

One of the tragedies of the British aluminium industry is that the producers in this country have never paid sufficient attention to research. They started with a process requiring a very special class of raw material which is not available in the British Isles, and they do not appear to have made any serious attempt to modify this process or to develop new processes to permit the use of such domestic ores as are available. As a matter of fact, I doubt very much if the English producer companies have, during the whole of their existence, spent on research a fraction of the amounts spent for this purpose by the independent aluminium alloy fabricating companies.

Considering the millions now being spent on shipping aluminium and bauxite to this country, with the attendant risk of loss of ships and cargoes by enemy action, it would seem reasonable for the country to spend even very large sums of money on research and plant to produce in this country the same quality of material from domestic ores.

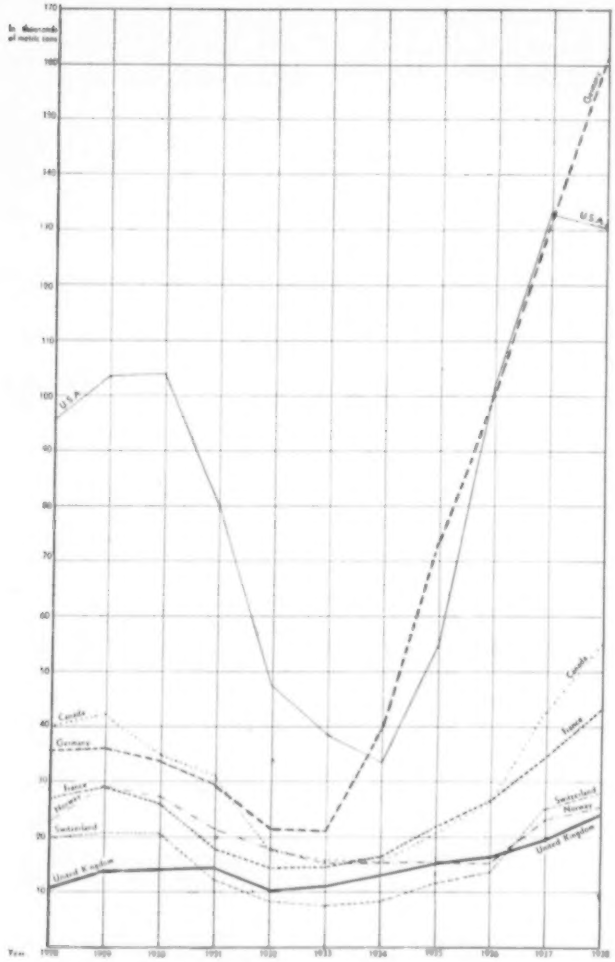
Faced with the task of providing aluminium for war requirements, and armed with the knowledge that ample supplies of coal are available for the generation of power, intensive research should be carried out to provide processes which could utilise available bauxite deposits and any successful process so developed should be assured of unlimited backing even if it at first proved more expensive than existing processes.

I am sure that had a fraction of the vast sums now being sent overseas to pay for imported aluminium been spent on increasing domestic aluminium production, as was done in Germany, we should have been assured of the greatly increased supply of cheap aluminium, which is the first essential for maintaining our greatly expanded fabricating industry after the war.

Given the conditions outlined above, and on the assumption of a reasonable price for aluminium, I have no anxiety about the future ; indeed, I believe that it is only the price factor which has so far prevented the wholesale use of aluminium and its alloys on an infinitely greater scale than that to which we have been accustomed. The accompanying graph, illustrating the production of aluminium in the leading producer countries during the period 1928-1938, reveals some interesting facts.

The tremendous improvements which have been effected as a result of the extensive research and development work conducted by the alloy manufacturers and fabricating industries, have removed most of the technical objections to the more general use of light alloys in all industries.

Great advances have been made in the development of high-strength and corrosion-resisting alloys. Fabricating processes have been vastly improved, and new protective surface treatments give beautiful and permanent colourings. Advances have also been made in methods of jointing, but in this field there remains much to be done. Riveting is still the standard method of joining stressed light alloy components. Some measure of success has been achieved with spot welding, but so far the size of the parts which may be so joined is strictly limited. Considerable improve-



Graph showing progress of production in the main producing countries.

ments must be effected in welding technique or the development of new jointing processes giving equivalent results before the uses of aluminium, especially in the mass production industries, can be fully exploited. In this field alone there exists a great opportunity for some really important research work.

Post-War Applications

During the war the industry has devoted the whole of its energies to the production of materials for aircraft construction to the exclusion of all other pre-war applications. I do not expect that with the advent of peace aircraft production will cease entirely ; presumably military planes will still be required, although in greatly reduced numbers, while the manufacture of aircraft for civil purposes should provide a quite considerable outlet for light alloys. There will also be a return to the many uses of aluminium which existed before the war. There will, however, have to be a very great increase in the applications of aluminium, if our great fabricating plants and their many thousands of workers are to remain in employment.

The light weight, corrosion resistance, and high strength of modern light alloys make them particularly suitable for structural and decorative applications in shipbuilding ; in fact, a number of very successful applications had already been made in this field before the war, but the high price compared with that of the old-established materials has so far prevented the vast potentialities of this market from being exploited to any appreciable extent.

The situation with regard to architecture is similar, and although aluminium and its alloys have been used quite extensively for decorative purposes in commercial buildings, the relatively high price has precluded their use on the scale which their properties and appearance merit. The period of post-war rehousing and reconstruction should present a unique opportunity to establish the light alloys as materials of building construction. I am sure that, provided the situation is handled properly to ensure that the right alloys are used for the right application, and provided these materials are made available at a competitive price, aluminium and its alloys will find a lasting market in the building industry and in the plumbing, central heating, furnishing, and other ancillary industries.

The transport industries cry out for light-weight construction to reduce dead weight and increase carrying capacity. It is to be expected that after the war a more urgent need for economy will make it necessary for both road and rail transport industries to reduce the cost per ton carried to a minimum. It will be necessary for them, therefore, to reduce drastically the dead weight of locomotives, wagons and road vehicles, and to do this they must turn to light alloys for assistance. This factor will also have repercussions on the construction of containers for the transport of liquids. Aluminium and its alloys will be used to an even greater extent to reduce the dead weight of milk churns, beer barrels, and containers and tanks for the transport of certain acids, oil, petrol and other liquids transported in bulk.

These and other new applications, together with the well-established uses, such as for cooking utensils, electrical transmission lines, automobile engine parts, etc., will form a huge potential market, which, subject to the lowering of prices to an economic level, should ensure the continued prosperity of a growing aluminium industry.

Hiduminium Technical Data

Since the initial development of the series of Hiduminium R R high-strength cast and wrought aluminium alloys in 1927, considerable progress has been made. They were originally developed by Hall and Bradbury, of Rolls-Royce, Ltd., in response to increasing demands for higher strength light alloys, and, in particular, for the Rolls-Royce " R " Schneider Trophy engine. During the past 14 years these alloys have been subjected to intensive development, and the range has been increased to cope with modern engineering requirements. The technical data of the complete range of these alloys are incorporated in this new publication, which replaces the data sheets, which have been issued from time to time, and presents the fullest details, including chemical composition, physical properties, mechanical properties, properties at elevated temperatures, etc.

In addition to the well-known R R series, this book also includes the more recent Anticorodal series, such as Hiduminium 15, 23, 33, 35, 40, 42, and 45, which were introduced to meet the ever-increasing demand for alloys which combine high corrosion resistance with—good mechanical properties. The book also includes a very useful index to specifications, both D.T.D. and B.S.I.

The object of this book is to place before the designer and draughtsman the full details concerning Hiduminium aluminium alloys in the clearest possible form. For this reason each alloy is presented across the inside of two facing pages, so that all the necessary information regarding the properties of a particular alloy are available without turning over a page. Further to ensure a flat-opening book, a spiral binding of an improved type is used. Additional information sheets will be issued from time to time, and provision is made for their inclusion at the back of the book.

Copies of this useful book may be obtained gratis on application to High Duty Alloys, Ltd., Slough.

Copies of " Aluminium Alloys," from the book by Prof. Zeerleder, an authority on aluminium and its alloys, are also available from High Duty Alloys, Ltd., but the firm ask applicants for this volume to state the industry in which they are engaged, or, if students, which profession they are studying.

The British Aluminium Industry

Trends of Development Likely to Affect Post-War Activities

By H. F. James

Development trends in the aluminium industry are very promising; in spite of its phenomenally rapid growth and the present abnormal conditions there appears to be no insurmountable obstacles to further growth when normal conditions are restored. Suggestions are made for research with a view to widening the scope of aluminium and its alloys, and attention is directed to economic aspects which will have a great influence on the progress of the industry as a whole.

THE light alloy industry is outstanding amongst those which have expanded on a large scale to meet the war needs of the armed forces.

Before the surge of metal aircraft construction which began with the pre-war rearmament programme, producers of light alloy semi-manufactured materials were concerned chiefly with supplying, sometimes in a rather passive way, such relatively small quantities of sheet, extruded sections, castings and forgings as aircraft constructors found themselves compelled to use in order to save weight.

There were, of course, notable exceptions to this, important examples being new applications of the aluminium-magnesium alloys in ship and rolling stock construction; the remarkable advance in the accuracy and strength of pressure die-castings; improved technique in the casting of fine grain billets and the development of ductile, high-strength castings. Such applications, although of considerable significance and importance, were, it must be noted, confined chiefly to castings. In general, however, it could not be claimed that any really outstanding progress had been made with the stronger alloys since the introduction of duralumin and "Y" alloys, and it seems that insufficient attention had been given to the formulation and carrying out of original research into metallurgical or manufacturing problems, connected with alloys of aluminium and magnesium. The writer would emphasise here that the foregoing statement is not intended to belittle in any way the practical development work conducted by several manufacturers with variations and derivatives of duralumin and "Y" alloys.

Aircraft constructors in this country did not, on the whole, employ all-metal construction until comparatively recently. The factors which contributed to this tardiness in recognising the merits of all-metal stressed-skin designs are too numerous to be reviewed in detail here, but there is no doubt that lack of adequate support and encouragement from the various Government offices concerned was one of the factors responsible.

It must also be pointed out that the high cost of duralumin proved a serious disadvantage when the material was brought into competition with steel—a disadvantage which was considerably accentuated by the fact that steel producers had recently completed intensive investigations into problems concerning high-tensile and stainless alloys, fabrication processes such as pressing and drawing, welding technique, etc. It was, in consequence, perhaps not surprising that British aircraft designs in light alloys were somewhat slow in maturing, particularly since at the time concerned the British aluminium industry was still more or less in its early stages of development.

When, however, the change-over to all-metal construction was made, the aluminium industry was confronted with a vastly increased demand for supplies of alloys, this being due, in some part to the actual change-over, but to a far greater extent to the quantities needed for the expansion of the Royal Air Force. This entailed a considerable—and necessarily rapid—expansion of the whole industry, involving the construction of new factories with the necessary equipment and personnel.

It is interesting in passing to compare the effect of the rearmament programme on the light alloy industry with that on the steel industry. In the latter, no erection of extra plant was involved. The problem merely resolved itself into the arrangement and working of additional shifts, and in some cases the bringing into operation of idle equipment. That no such simple solution of the problem was possible in the light-alloy industry is evidenced by the fact that one concern rolling duralumin sheet has increased its output by more than thirty times in a little over two years.

In these circumstances it is not surprising that during the war there has been little time for development work on light alloys, particularly with regard to the higher-strength materials. Indeed, it must be admitted that as yet no real progressive tendencies have manifested themselves. The advantages gained as a result of the present high rate of production are confined almost entirely to improvements in technique and machinery—for example, rolling, extruding and forging processes and the necessary equipment.

As regards the quality of material being produced under the stress of present conditions, it must indeed be admitted that tendencies have at times existed towards the relaxation of pre-war standards, in order to avoid scrapping material which did not comply with the prescribed specifications. Such tendencies have, however, been kept under the strictest surveillance and confined to cases in which ample justification existed and in which no danger of failure of the finished product would be likely to occur as a result.

An appreciable amount of the space available for this review has been devoted to the effects of the British air expansion programme, since the conditions brought into being as a direct result of it must inevitably have a considerable effect on the industry during the post-war period. The production of aluminium in this country and in Canada has been vastly increased. Equipment for producing and working the various alloys has been correspondingly augmented, and very large numbers of skilled and semi-skilled personnel have been absorbed who are rapidly becoming specialists in the various branches of the work. In addition, the aircraft industry has recruited even larger numbers of workers whose technical skill is based solely upon aluminium as a constructional material.

In most industries the post-war effects of such an expansion would be well-nigh disastrous, but providing that certain essential measures be adopted, it is the writer's firm conviction that the aluminium industry should be able to sell in peace-time all the added output that war-time conditions have made available, since in the almost endless variety of applications where lightness of weight is an advantage and the other qualities of the jetal can be utilised, there is scope for the employment of aluminium or one of its alloys.

First and foremost must be considered the question of price. The disadvantage of the high price of aluminium as compared with that of steel has already been mentioned. If aluminium alloys are to become competitive with steels in the more important fields of application, this disad-

vantage must be removed by a drastic reduction in price. The full extent to which price reduction is possible can, of course, be determined only with reference to numerous contributory factors, many of which are yet indeterminate: but every advantage must be taken of improved manufacturing methods and the consequent reductions in cost.

With regard to technical factors, the points at issue are very clear. The higher strength alloys must be developed and their potentialities stressed to the maximum extent, particularly in every large-scale structural field where lightness is a consideration. Much cheaper medium-strength alloys of the duralumin type, such as will be competitive with steel as well as all other non-ferrous alloys, must also be put on the market in the form of sheet, extrusions, forgings and castings. It is important, particularly in connection with the high-strength alloys, that welding technique be improved considerably; this being essential if the materials are to compete with high-tensile steels.

Exhaustive research will be necessary into the fatigue resistance of the higher strength alloys, and into the effects of internal stresses set up by heat-treatment processes designed to increase the strength of the materials. This is particularly necessary in the case of parts subjected to vibration in service, since at present it is impossible to use such parts in the "maximum strength" condition owing to their low damping capacity. The somewhat retrograde step, therefore, of modifying the heat-treatment—and reducing the mechanical strength—has been found necessary to avoid failure.

Methods of inhibiting corrosion also call for continued investigation, particularly with regard to the effects of methods of production, treatment or forming on the alloy structure and properties, whilst an increasingly urgent need exists for the standardising of anodising processes. Fortunately, signs exist that moves towards this latter end are already well under way.

One great advantage which has accrued from the rapid production required in war-time is that the need for standardising methods of forming, pressing and drawing light alloy materials has at last been fully realised. The aircraft industry has in the past suffered particularly from a failure to appreciate this, with the result that nothing like complete advantage could be taken of the full range of alloys available. It has fallen to the lot of the alloy manufacturers to take the lead in pointing out the reason for failures experienced, the need for modifying and improving equipment, and the desirability of using, for a specific purpose, some more suitable alternative material. The experience gained in this particular direction should prove to be of considerable value to the industry in the future.

A further direction in which a need for standardisation has been fully realised lies in the production of constructional sections. At one time an argument frequently advanced in favour of extrusion—a process particularly successful in the light-metal industries—was that sections of any desired profile could be readily supplied. This, of course, was very true, but to cater in such a manner for individual cases was, as has been well demonstrated by experience gained as a result of the air expansion programme, wasteful in the extreme. A considerable measure of standardisation in the sections supplied to transport equipment designers, architects, etc., will undoubtedly be a welcome feature of the industry in the future. It will assist both suppliers and consumers towards a more economic solution of their joint problems.

Problems regarding the efficient utilisation of scrap have also, to some extent, been solved as a result of war-time experience. In the past the tendency was to use all aluminium alloy scrap for the production of cheap casting alloys of the so-called "secondary" type. The need for economy in supplies of aluminium has, however, drawn attention to the fact that high-grade scrap should be recovered as such in an identifiable form and used again in the production of high quality alloys. Official recognition has now been accorded to the fullest use of this practice, which will, of course, make an appreciable contribution towards a satisfactory solution of the economic factors already mentioned.

It is not too early now to direct attention to the likely post-war applications of aluminium. As is well known, all supplies of aluminium produced or imported into Britain during the war are being used for the production of war equipment, with the result that the normal markets for aluminium in this country have, for the time being, disappeared.

At one time, in the early days of the war, it was thought that this might result in the capture of such markets by substitute materials which would be difficult to supplant, but fortunately, up to the present, few signs have appeared to justify this. In fact, the widespread publicity given to aluminium as a result of its vital importance to the war effort has resulted in its merits being recognised on a very much wider scale than hitherto, and at present all indications point to the fact that many of the old markets will return immediately the war is over.

Amongst such markets will undoubtedly be those concerned with hollow-ware and foil. This will account for a substantial tonnage which will, in all probability, even exceed the total achieved in pre-war days. But it must be pointed out that such totals will represent much smaller percentages of the production capacity of the industry than was the case before the war.

The aircraft industry will naturally continue to use aluminium, although it is impossible to say at the moment on what scale civil aviation will progress during the immediate post-war period. Then in internal combustion engines and in all types of road vehicles the metal can be expected rapidly to return to its former firm position. In this latter connection, as in the case of hollow-ware and foil, it must be remembered that the making up of deficiencies resulting from the present ban on the use of aluminium is likely to absorb large quantities of the metal.

In rail and marine transport, some ground will probably be found to have been lost. This will necessitate an intensive drive at the outset, but if backed up by a reduction in price, these particular fields will almost certainly absorb increasing quantities of aluminium as time goes on.

The electrical and chemical industries, in which appreciable quantities of aluminium were used for specialised purposes, may be expected to revert to the pre-war position, and steady subsequent increases in the tonnage absorbed are probable. In architecture, the almost ideal combination of properties possessed by the metal for decorative purposes, should result in aluminium alloys, in a variety of forms, being used on a large scale in the rebuilding of the bombed areas.

Even if these important markets are held and increased, however, it will still be necessary for further intensive effort to be made if the full output of the industry is to be absorbed. To do this it is to the higher strength alloys and their uses that the industry must turn to secure the wider markets which are its essential prerogative. It is, therefore, essential, even at the present time, to carry on experimental development work and market research much more intensively and on a far larger scale than has been envisaged hitherto.

In conclusion, it is not inapposite to mention another aspect of the future of the light alloy industry which should not escape attention when provision for the post-war period is being considered. The productive capacity of the industry has been increased enormously, and albeit the expansion has been in response to the stimulus of war demands, the light alloy manufacturers should be prepared to bear a measure of responsibility for the future welfare of their greatly increased numbers of employees. Some of these may return to other occupations when the war is over, but many doubtless hope this young industry will provide them with a livelihood in peace-time.

Trend in Manufacture and Future Applications of High Strength Aluminium Alloy Extrusions

By R. Worsdale

High-strength aluminium alloys have been tested under many diverse conditions of service, and have proved their reliability and utility beyond any reasonable doubt, but long-term development is necessary to ensure that the aluminium industry will make a worthy contribution to the future progress of engineering in its various branches. In this article the advantages of light metal extrusions for structural engineering are emphasised.

IN discussing the trend of manufacture of high-strength aluminium alloy extrusions which can conveniently be referred to as structural sections, due regard must be paid to the censorship requirements. Since for the present all aluminium alloys are reserved for Service uses, mainly aircraft, little can be said in detail of the manufacturing developments which have taken or are taking place. They must for security reasons remain undisclosed.

This much can be stated. All plants are fully engaged in producing the utmost possible quantity. Consequently, all methods of production have been closely overhauled, and many improvements (some of a minor character) introduced. These have enabled production to be stepped up, but will be doubly important when normal conditions return. Furthermore, it is essential in the national interest for there to be at least duplication of production of every section required. This fact has had the effect of a certain amount of standardisation and simplification, since each and every manufacturer must be able to undertake all sections required on any aircraft, in so far as their equipment allows. Such requirement necessarily restricts those manufacturers who have developed the production of the more complex sections. The latter, while taking somewhat longer to produce, particularly in finishing operations, do save constructors' time in subsequent operations.

The authorities who control, to some extent, the activities of our aircraft designers are therefore discouraging the use of sections which appear complex in contour or design. That such action may increase production hours in aircraft factories, although taking somewhat longer in extrusion manufacturers' time, where labour is generally cheaper and less skilled, appears to be completely overlooked. Quantity production of extrusions is not necessarily synonymous with quantity production of aircraft, particularly in those cases where machining or additional joining operations are involved at constructor's works.

That there are some interesting developments in "cold storage for the duration" is true, but equipment necessary for their full development is wanted for more urgent national needs. There the development picture must remain.

What of the Future?

With the rapid development of high-strength alloys, which have been tested under all conditions of service in aircraft and have proved their reliability and utility beyond any reasonable doubt, there is no reason why extrusions should not be used in structural engineering practice, whether marine, civil, transport or architecture: in fact any field of engineering where lightness with strength is necessary.

Once the general characteristics of the various alloys selected are understood, design can proceed along normal lines. Savings in weight can quite readily be effected up to 40–50%, whichever way a structural component may be stressed, and still meet the specified requirements.

It is quite unnecessary, when designing structures in light alloys to design for steel and then substitute the nearest standard sections in light alloy. The fact that nearly all the largest sizes of sections can be produced by extrusion rather than by rolling adds impetus to their use. Sections which can be inscribed in a 16 in. circle, and weighing up to 25 lb. per ft., or heavier in some cases, are well within the compass of present extrusion equipment. The finished heat-treated length is governed by the size of billet used, and heat-treatment facilities at manufacturer's works. The cost of extrusion dies is not to be compared with the cost of rolls for steel sections. The cost of such dies, spread over a few tons of metal required for any reasonable size

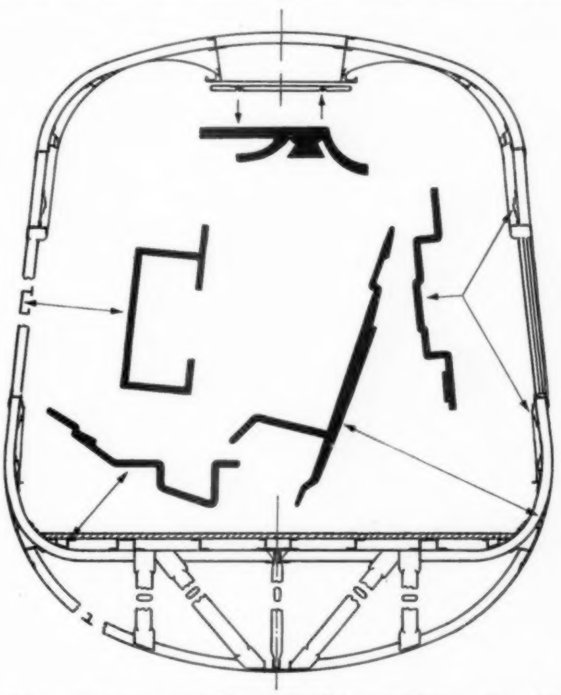


Fig. 1.—Some special extruded sections for the articulated triple car set built for the Union Pacific railroad, U.S.A.

project, would be very small indeed, and would enable a more efficient design to be evolved. A designer can obtain any section he chooses, within reason, and, moreover, he is not limited to a table of standard sizes. Here it should be pointed out that the lower modulus of elasticity of aluminium alloys should be carefully taken into account. For instance, beams should be of deeper section than the equivalent in steel to utilise the metal to the best advantage. Little change is necessary, however, in beam dimensions when increased deflection is not of great importance.

For marine work, extrusions can be used with safety, since light alloys are now available which combine corrosion resistance with strengths quite equal to the usual constructional materials hitherto used. Furthermore, methods of protection are now much improved, and more widely

understood. Hence it follows that the more advanced naval architects, desirous of lightening the superstructure of large vessels, can specify their structural sections in light alloy extrusions.

For the framework of smaller vessels, such as private yachts, police patrol boats, and the like, extruded sections can quite readily be adopted without any fear of failure, provided the correct type of alloy be selected. Space does not permit detailed examples, but those readers engaged in marine work will be familiar with the published data on

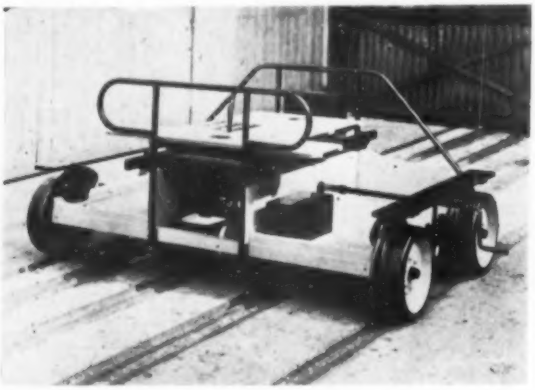


Fig. 2.—A petrol-driven inspection car made for one of the South American railways by Messrs. D. Wickham and Co., Ltd. The main frame is made entirely of aluminium alloy angles.

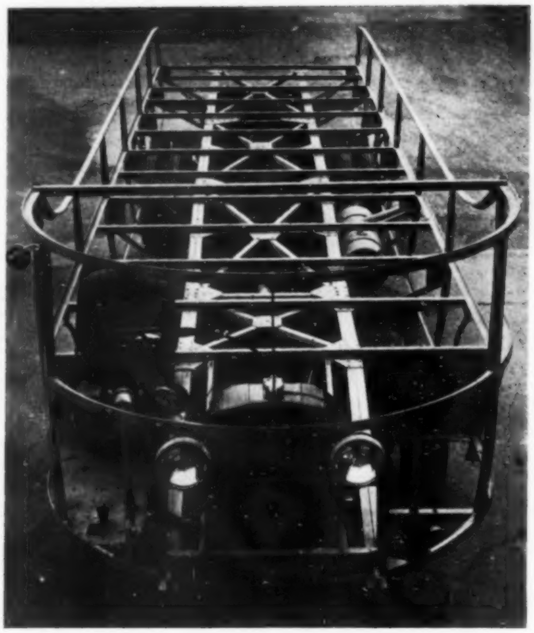


Fig. 3.—A 6-wheel commercial vehicle, 30 ft. long, constructed by Jensen Motors, Ltd., for Reynolds Tube Co., Ltd. Extruded sections were used entirely for the framework and chassis.

the use of light alloys, which has appeared from time to time in various technical journals here, in Europe and in America.

The fact that shipbuilders are awakening to these advantages is evidenced by the remarks made by Mr. W. A. Woodeson, in his presidential address to the North-East Coast Institution of Engineers and Shipbuilders, October, 1940, and also by Mr. C. A. Hardy, B.Sc., before the Institution of Engineers and Shipbuilders of Scotland recently.

Similarly for architectural work, structural sections can be employed with safety. In the construction of high-storey buildings, the upper floors might well employ them, particularly where the weight of a building on foundations is a problem. The increased cost of light-alloy sections might be justified on this fact alone, added to which is the lower erection costs on account of the lighter weight of material to be handled, points well worth considering.

Another field in which sections are making headway is in the construction of commercial and passenger transport vehicles, and railway rolling stock. In Continental countries, notably Switzerland and France, and also in America, many examples could be quoted of their extensive use, with great success. To give one example of railway work, there is the articulated triple car set, No. 10,000, built for the Union Pacific railroad, U.S.A. A number of special sections were made for this train to obtain the most scientific design, some of them being somewhat complicated. Fig. 1 gives an idea of the sections employed. Readers interested can obtain fuller details of railway practice in this respect from the bulletins of the International Railway Congress Association, January, 1937—*The Railway Age* and the *Iron Age*—in all of which journals many articles have appeared from time to time over the last six to seven years.

Another railway example is shown in Fig. 2, a petrol-driven inspection car made for one of the South American railways by Messrs. D. Wickham and Co., Ltd. The main frame is made entirely of aluminium alloy angles, which replaced similar angles in steel. Repeat orders for these cars have proved their reliability under difficult service conditions.

In commercial and passenger vehicles some progress was being made prior to the war. Two examples personally known to the writer can be quoted. Reynolds Tube Co., Ltd., two years ago were experiencing difficulty in transporting very long lengths of light alloy extrusions to aircraft works and decided to try and solve their problem by the construction of a special vehicle. Jensen Motors, Ltd., were commissioned to build it, the stipulation being that it should be the maximum legal length 27 ft. 6 in. for a four-wheeled vehicle, weight under 50 cwt., to permit a speed of

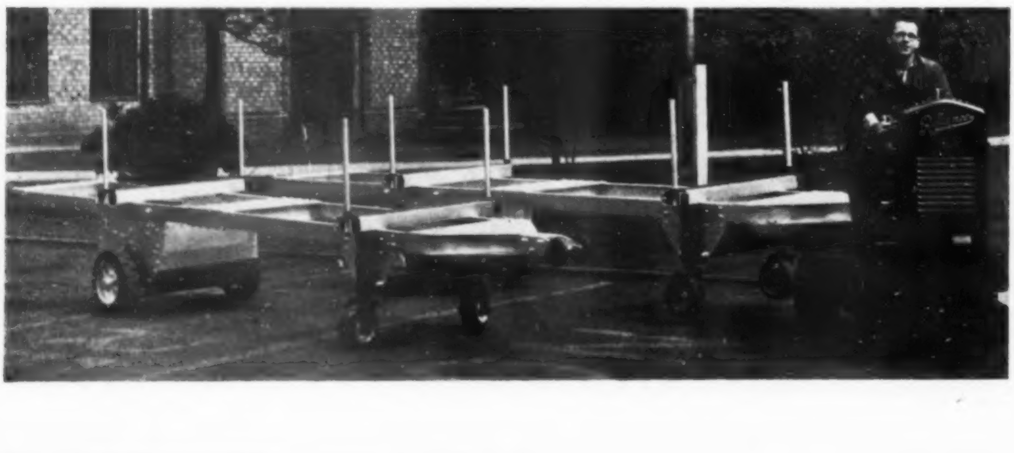
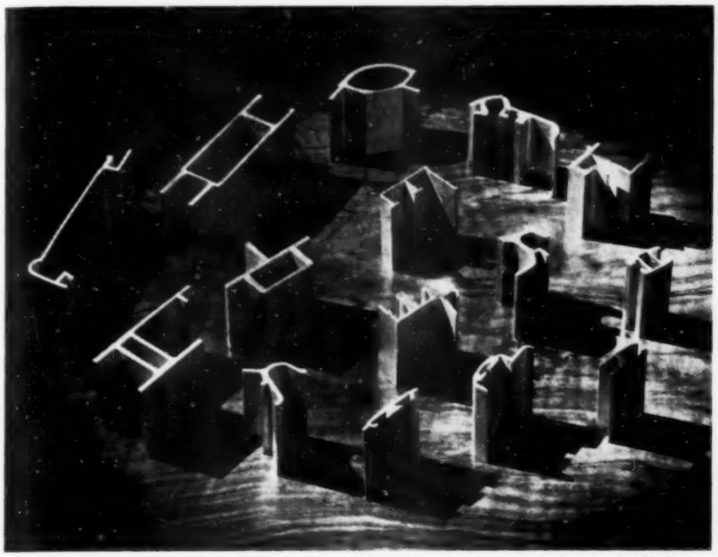


Fig. 4.—Inter-works articulated trailers, in which considerable saving of weight is effected by using extruded sections.



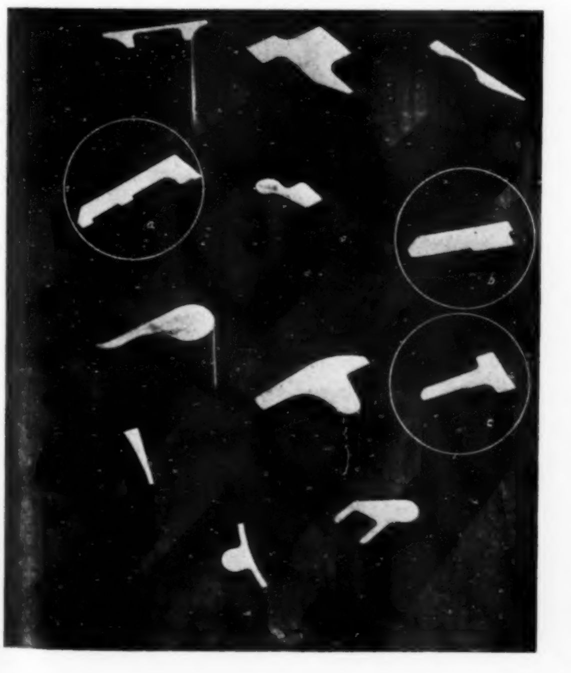
[Courtesy of Aluminium Industrie (A.G.), Neuhausen.

Fig. 5.—Examples of sections used in Switzerland on commercial vehicles.

30 miles per hour. Extruded sections were used *entirely* for the framework and chassis. The unladen weight was 46½ cwt. The maximum load, 4½ tons. Powered with a Fordson "V 8" 30 h.p. engine, this vehicle has been in service since February, 1939. Travelling in all weathers, through blackouts and blitz, it has covered over 55,000 miles with complete satisfaction, and is still running well. Subsequently, in October, 1939, a further vehicle, this time a six-wheeler, 30 ft. long, also under 50 cwt., was brought into operation, and is illustrated in skeleton form in Fig. 3. This vehicle has covered over 34,000 miles, with equal satisfaction.

Another instance is articulated trailers for inter-works use. These are shown in Fig. 4. A saving in weight of over 3 cwt. on a normal steel weight of 9 cwt. was effected. These trailers have been in use for nearly three years, with complete success.

Fig. 6.—Special extruded sections which either eliminate machining or reduce it considerably.



Designers can further exploit the advantages of light alloy extrusions by combining two or three sections into one, thereby simplifying construction, reducing costs, and giving a better appearance. Examples of sections used in Switzerland on commercial vehicles are given in Fig. 5.

While the foregoing instances have applied to the major industries, there are many others in which the lightness and strength of aluminium alloy extrusions can be used. Fig. 6 gives examples of sections used in other spheres. The three sections (shown ringed—*a*, *b* and *c*) are needle bars which have replaced steel on high-speed knitting machines. Their use enabled the operating speed of the machine to be increased considerably.

Other practical examples are crane jibs, travelling cranes, fire escape ladders, etc. Readers will find design data of considerable interest in the paper read by Mr. Edgar T. Painton, B.Sc., in 1935, before the Scottish Branch of the Institution of Structural Engineers.

Another use which is capable of further development is that of extrusions for machined parts. Many machine hours have been and are being spent in milling, etc., small parts from round, rectangular or square bars. Time can be saved by designing special sections for the purpose, which, if not eliminating machining entirely, reduce it considerably. Fig. 6 gives a few examples. All those sections illustrated were previously machined to shape, either in aluminium alloy or other metals, from rectangular bar. The time saved can well be imagined.

While many sections are used in straight lengths, it must not be overlooked that they can be manipulated to a variety of shapes once the technique has been acquired. Fig. 7 illustrates a miscellaneous collection of all types of manipulated sections. Such practice should appeal to many designers, particularly for transport, both road and rail, where by the exercise of their ingenuity many problems of modern design can be solved.

All the foregoing practical examples show what has been or can be accomplished using the high-strength aluminium alloy extrusions as structural members, but there are other factors which merit consideration.

One of these is that of economics. While some progress in the utilisation of extrusions as structural sections has been made, not merely based on a passing phase or whim, but on sound economic considerations, it must be stated as a fact that the first cost of the virgin metal from which all alloys are made has precluded its use in many applications, particularly in the competitive field of structural engineering. When it is realised that sections in high-strength alloys cost in the neighbourhood of 3s. per lb., whereas structural steel sections cost probably less than 2d. per lb., the advantages to be gained by the lightness of the metal are far outweighed by its cost, the ratio being 6 to 1. It is on these lines that the producers of aluminium must do some hard thinking if true realisation of the aluminium age is to be attained. While it is improbable that the cost of production of virgin aluminium will ever be brought as low as iron or steel, a reduction of 30–40% below the present price could make a vast difference, and would be as revolutionary in the aluminium industry as the introduction of the Bessemer process was to the steel industry. A reduction of this order will be necessary if present manufacturing facilities are to be kept reasonably employed after the war, even allowing for the vast reconstruction schemes which will be necessary everywhere and in every field. Given a price *circa* £70 per ton for alloys of first-grade, and allowing for other metals to fall to prewar levels, the price at which extrusions could be produced would be competitive with structural steel in many applications, but not all, taking into consideration the inherent advantages of the metal. That the producers of aluminium

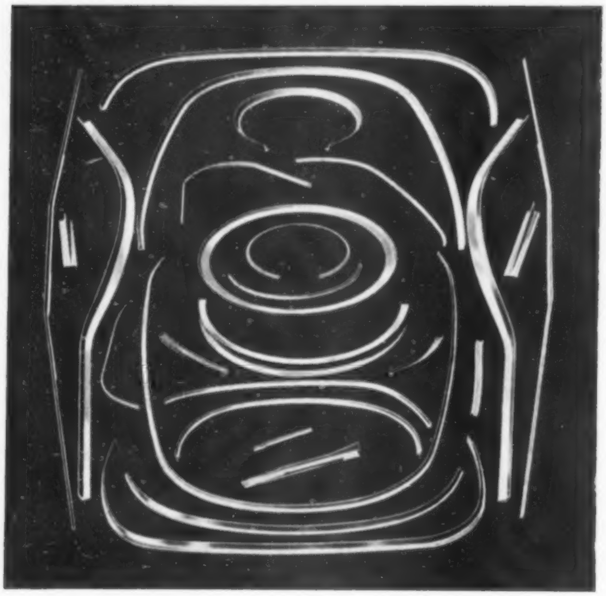


Fig. 7.—A miscellaneous collection of all types of manipulated extruded sections.

are fully alive to this fact, the writer believes to be the case, but no harm will be done by stating the case here. The price now ruling in America, which is lower than in this country, gives a pointer in this direction. That the whole field is ripe for development no one can deny, which leads up to the second factor—the innate conservatism of many British engineers in their reception of new materials and ideas. Many experiences of the writer, over a number of years, have indicated a limited outlook on the part of those responsible for initiating design and capital expenditure. Whereas in America and elsewhere countless instances are on record where first cost, say, of transport vehicles using aluminium alloys has been twice or three times that in other materials, the saving in operating costs or increased pay-load has within a few months saved the additional first cost and in final analysis given higher returns. In this country the reverse appears to be the case. The capital cost appears to be always the prime consideration, other advantages being entirely disregarded. That moves are being made in some industries has already been indicated earlier in this article, but they are still too few.

While the equipment, knowledge and technique is possessed by all the leading manufacturers of extrusions and structural sections in this country, and who, with complete justification have absolute faith in the suitability of their materials for the applications indicated herein, there does exist a need of more designers to become aluminium minded, if aluminium alloys are to take their rightful place in the post-war economic life of the country.

It is true that the manufacturers are alive to the need for long-term development and are ready to cope with it now. Even in the midst of the present struggle most are retaining nuclei of trained specialists, who are devoting their time to post-war problems as they will affect the industry, and it is for designers and engineers to take advantage of their services if we are to be in the van of post-war development and progress.

The Spot Welding of Light Alloys

THE investigation described in this Report* is of an exploratory nature designed to ascertain the strength and behaviour of spot welds in light alloys under present conditions. The first part dealt with spot welds made between sheets of equal thickness in uncoated duralumin-type alloy 17 ST, and aluminium-coated duralumin (Alclad) in 16- and 20-gauge thickness. Spot welding was carried out by three different firms, each using the machine settings which they had found in practice to be suitable for producing good welds in the particular material and gauges concerned. Static shear and fatigue tests were made on specimens "as welded," and after normal heat-treatment and age-hardening. The average values in static shear were found to bear a close relationship to the strength of rivets of proportional size. The divergence between the maximum and minimum values varied from $+4\%$ to -5% to $+29\%$ to -12%, the variation bearing no obvious relationship either to the size or average strength of the welds.

Normal heat-treatment of the material after welding was found to increase the static shear strength by 17–57%.

Experiments on spot welds made with a machine fitted with "programme control" equipment indicate that the heat-treatment resulting from this process increased the static shear strength by approximately 16–23%. The divergence between maximum and minimum values was not appreciably reduced.

The results of fatigue tests on single spot specimens appeared to be somewhat low in relation to the static shear strength, and no great improvement was obtained by heat-treatment of the material after welding. Exposure of specimens of the two materials to sea-water spray for six months demonstrated the marked superiority of Alclad over duralumin-type alloy in withstanding corrosive action; the aluminium coating of the clad material was almost unaffected, whereas some of the duralumin-type specimens broke apart during exposure or subsequent normal handling.

Spot welds between sheets of dissimilar thickness varying from 24- to 14-gauge, gave strengths comparable with those between sheets of similar thickness. A limited number of spot welds joining sheets to extrusions gave shear values comparable to those between sheets.

The results of tests on aluminium-magnesium alloy M.G. 7 indicated an increase of approximately 7% in the static shear strength of single spot specimens—the fatigue strength being equal to that of spot welds in Alclad and higher than that of welds in the duralumin-type alloy.

The spot welds in M.G. 7 had a high resistance to corrosion—the resistance to attack by sea-water being similar to that of spot-welded Alclad and very much superior to that of spot-welded duralumin-type alloy.

The effect of spacing of welds on their static shear strength was investigated. Single welds cut from rows of welds in 20-gauge duralumin-type alloy sheets with spacing from $\frac{5}{8}$ in. to $1\frac{1}{4}$ in. showed a slight increase in shear strength with an increase of spacing up to approximately $1\frac{1}{8}$ in. The strength per inch of joint is, however, greatest for the closest spacing.

With spot-welded light alloys of the heat-treatable type, such as Alclad and duralumin-type alloys, it has been found that rupture, under fluctuating loads, occurs through the softened band of the sheet in the immediate vicinity of the weld. It was thought possible that the fatigue strength of the spot welds in the non-heat-treatable alloy M.G. 7 might be of a higher order, but the results show that the values obtained are no greater than for Alclad material.

The authors conclude that the values of static shear failing loads shown in the Tables indicate that the average strength of spot welds is closely comparable with the strength of suitably sized rivets for the same thickness of material, but there is a wide divergence (as much as $+29$ to -12%) between the maximum and minimum values, obtained from welds made with different machines, and even from the same machine and a given setting.

The fatigue values, although low, are generally more consistent, but as failure takes place in the sheet material the actual fatigue strength of the spot weld is not known.

* Report S/R 52 of the Welding Research Council of the Institute of Welding, 2, Buckingham Palace Gardens, London, S.W. 1. Price 2s. 6d. net.

The Practice of Marketing of Aluminium

By Robert J. Anderson, D.Sc.

The practice of marketing aluminium, more especially in respect of its technical and commercial details, has been dealt with rather scantily in the literature, and the purpose of this article is to give a broad view of the practice. Applications will also be considered briefly in order to show the range of the market. The marketing of aluminium and its manufactures is necessarily conditioned by the kind of products and their field of use and future developments will increase the range.

ALUMINIUM is sold in numerous forms which may be grouped for convenience of discussion in five main classes. These are: (1) Primary ingot metal (often called raw or crude); (2) scrap; (3) secondary ingot metal; (4) semi-manufactures; and (5) finished products. As to the first class, it may be noted that the bulk of primary aluminium now produced is the 99+% grade. Some intermediate aluminium alloys are made by a primary smelting process, but the total output is small. Both aluminium of industrial purity and many light aluminium alloys are included in the last four classes.

Aluminium ingot for remelting may be all-primary or all-secondary metal, or a blend of primary and secondary, with or without scrap, in varying proportions. Or, it may be a blend of primary aluminium and scrap or of secondary aluminium and scrap. These two statements also apply to light aluminium alloys in ingot form. Cast and wrought products, both aluminium and alloy, may be made of either primary or secondary metal, or different proportions of the two may be used in the manufacture. More or less scrap, or metal reclaimed from scrap, enters into the make-up of melting charges for the production of most manufactures, both cast and wrought. Such scrap may originate in the plants where the products are made, or it may be obtained from outside sources.

In aluminium nomenclature, pig is the term ordinarily used to denote the metal as cast from the reduction cell. It is remelted and refined, and usually blended, before being poured into the various kinds of ingots. Liquid aluminium from the reduction cell may, of course, be transferred directly to a holding furnace for different processing operations, rather than be run first into pigs.

The commercial problems of marketing aluminium and manufactures thereof include those encountered in the general field of trade since the metal, in one form or another, is widely employed in the production of both durable and consumers' goods. At present, the applications of aluminium are almost too numerous to recount, and the broad classification given above does not even suggest its great diversity of uses. An idea of the extensive market for aluminium and manufactures thereof may be gained, however, from consideration of the products advertised by a fully-integrated company. Some products include the following:

Ingots: Ingots, billets and slabs for wrought manufactures. Casting alloy ingot. Metallurgical granulated ingot.

Materials for fabrication: Rolled structural shapes, including angles, beams, channels, car channels, and zees. Extruded shapes and moldings for aircraft, architecture, railroad rolling-stock, truck bodies, bus bodies, etc. Rod and bar—round, rectangular, hexagonal, and special shapes for screw-machine stock. Sheared and sawed plates, rectangular and circular. Tank plates. Tread plate. Sheet—comprising Alclad, flat, coiled, corrugated, circles, reflector sheet, and roofing sheet. Handrails and fittings. Pipe and fittings (iron-pipe sizes). Tubing—round, square, streamline, and special shapes. Sand, die, and permanent-mould castings. Forgings. Pressings. Impact extrusion products. Draw-press products. Screw-machine products. Rivets, bolts, nuts, and nails. Machine and wood screws. Wire, including round, half round, oval, half oval, and flattened. Welding flux and wire.

Specialities: Barrels and shipping containers. Chemical and special apparatus. Kettles. Welded and riveted tanks. Job-shop products.

Automotive products: Pistons and connecting-rods.

Electrical conductors and accessories: Electrical cable, all-aluminium and A.C.S.R. (aluminium cable, steel reinforced). Cable fittings and accessories. Rigid conduit. Bus bars—flat, tubular, and rolled channel. Bus-bar fittings and accessories. Fuse wire. Magnet wire.

Powder and paste: Powder for paint pigment, printing ink, lithographic ink, rubber compounding, dusting, etc. Paste for paint pigment.

Packaging products: Bottle closures and bottle-sealing machines. Collapsible tubes. Foil—plain, printed, embossed, lacquered, and paper-mounted.

Various other manufactures might be mentioned.

The chief interests engaged in marketing aluminium in one or more forms are: (1) Primary aluminium producers; (2) scrap dealers; (3) secondary aluminium producers; (4) manufacturers of semi-finished material; (5) manufactures of finished goods; and (6) selling agencies. In respect of financial strength and dominant position in the markets the large producers of primary aluminium are the most important among these interests. Nearly all primary producers, either directly or through subsidiary companies, are manufacturers of most semi-finished and finished wares. Consequently, the marketing activities of these producers generally cover the entire field of sales, both actual and potential. On the other hand, the scope for marketing by other interests is much less extensive because their range of products is usually quite limited. For example, a non-integrated rolling-mill may produce only sheet and related semi-manufactures, and a foundry may make only rough sand castings. Also, not many so-called independent firms in the working-up branches of the aluminium industry can compete successfully against the fully-integrated concerns in the manufacture of most products. Moreover, as compared with the large primary producers, most non-integrated companies are weak as to financial resources. There are, however, some strong and outstanding interests among the independent firms, and some small companies engaged in the manufacture of specialities have been profitably managed.

In the marketing of aluminium and its manufactures

the practice of vendors is necessarily conditioned by the kind of products offered, and their field of use. Aluminium is employed in some form by most industries, and its principal applications may be summarised as follows: As castings and wrought parts for transportation equipment (land, air and water); cable for the transmission of electricity; cooking utensils; for machinery and electrical equipment, including household apparatus; building construction; as a deoxidizer in the metallurgy of steel; equipment for the preparation of chemicals and food; foil, mainly for wrapping; and powder, mostly for paint. The composition and properties of aluminium-base materials supplied for these various purposes differ markedly, depending upon the particular requirements. For the most part aluminium and its alloys for remelting, and in manufactured form are produced to conform with engineering specifications. Producers, manufacturers, consumers, military authorities, engineering societies, and other organisations have drawn such specifications. These are so numerous that they cannot be considered here.

It is evident, of course, that the finished product of one manufacturer may be the raw material of another. Aluminium sheet is the finished product of the rolling-mill, but the raw material of the utensil factory. Rough castings are the finished manufactures of a foundry, but are parts for further processing (as machining) and assembly by engine builders. Both semi-manufactured and finished goods may be made in some partly-integrated works. An example is that of a company which rolls sheet to supply its own utensil plant; it may also produce sheet for the general market. Some foundry companies may reclaim secondary metal from purchased scrap for use in the manufacture of their castings and also for sale in the market. In practice many intermediate products of both fully- and partly-integrated firms may be supplied as such to consumers, or to be further processed in the works where made in the manufacture of finished goods.

Apart from aluminium and manufactures thereof, various other materials are marketed by most primary aluminium producers. These include the following: Bauxite; calcined alumina; electrodes; aluminium hydrate, chloride, fluoride, sulphate, and other salts; sodium fluoride, fluorspar, synthetic cryolite, hydrofluoric acid, and miscellaneous fluorides; caustic soda; and lime. Some of these substances are raw materials required in the production of aluminium, and others are by-products. They are sold to numerous consumers in widely-diversified industries. Their marketing is beyond the scope of this discussion.

Primary Aluminium

Metal produced from ore by a smelting or electrolytic process, and subsequently refined or not, is termed primary. All primary aluminium is made by an electrolytic process. Some light aluminium alloys may be prepared by the same process, and a few intermediate alloys are produced by smelting (carbon reduction). The output of these alloys is small, however, as compared with that of primary aluminium.

At present, there is practically no open market in primary aluminium, and futures are not sold. The producers market ingot metal directly to consumers, or sell through subsidiary organisations. Excluding a small number of selling agents in international trade, brokers and jobbers have never been important in the marketing of primary aluminium. Practically all middlemen have now been eliminated from the home markets of producers. The not unreasonable position taken by the large primary aluminium producers is that it is to their advantage to sell directly to the user and only for immediate or definitely contemplated consumption. Thus, they are able to prevent speculation, do away with unnecessary intermediate handling, and eliminate commissions to middlemen. For these reasons it is held that direct selling is also in the interest of consumers.

In the marketing of primary aluminium the basis of grading is chemical composition. Several grades are made. The compositions of similar sorts vary slightly among the producers in different countries depending upon specifications, the ore used, method of preparing the alumina, and other technical conditions. But similar grades of the different producers are generally equivalent for practical purposes. The regular grades supplied are the following: (1) High purity, 99·9 to 99·99+% aluminium; (2) 99·5% minimum; (3) 99% minimum; and (4) 98 to 99% aluminium.

The content and kind of impurities determine the grade of aluminium. In practice, evaluation of the aluminium content is ordinarily based on the difference method of analysis. That is, the total percentage of two or more usual impurities (at least iron and silicon) is ascertained by chemical analysis and subtracted from 100%; the difference is taken as aluminium. Spectrographic analysis may also be made, particularly in the case of high-purity metal. Specifications generally define the allowable total amount of impurities and the maxima of certain ones. Aluminium which contains appreciable quantities of some impurities cannot be primary.

High-purity metal, containing up to about 99·99% aluminium, is still costly, and so far the output has been small. It is used for special purposes, particularly as a coating to resist corrosion. Metal containing 99·5% minimum aluminium is specified for some applications including electrical conductors and foil. The 99% grade as supplied at times by some producers may contain up to about 99·6% aluminium. Ordinary 99% minimum grade is used generally for rolling sheet and the manufacture of numerous wrought products. It is also employed in preparing various alloys for both casting and working, especially alloys to be heat-treated. The 98 to 99% grade is used mostly in foundry practice for making casting alloys. It is obvious that the grade of primary aluminium which can be applied for the preparation of alloys is determined by their composition. The 98 to 99% grade cannot be used for some alloys on account of its relatively high content of iron. Aluminium produced from alumina made by the Haglund process contains too much titanium to be employed for electrical conductors, but is quite suitable for most other purposes.

In the production of primary aluminium rather small quantities are tapped from the reduction cells at intervals. This metal contains more or less admixed oxide and electrolyte. Also, the composition varies among cells, and is not constant for any one cell. Metal from the reduction cells is normally remelted or transferred directly to large holding furnaces for refining and blending. In this way the non-metallic impurities are removed, and large batches of relatively uniform composition are successively produced. Off-grade primary metal may be suitably blended with plant scrap or secondary material for the production of 94-to-98% aluminium. This grade is used mainly in the deoxidation of steel.

Light aluminium alloys for casting or working are supplied in ingot form by producers of primary metal. Such alloys made by the addition of the required alloying metals to primary aluminium, as well as those produced by electrolytic reduction, are called primary or virgin. A complex ferro-silico-aluminium alloy known as Alsimin is made by the carbon reduction of ore. This alloy is relatively lean in iron, but rich in aluminium and silicon. It is used for the deoxidation of steel.

Aluminium ingot is the common form of the raw metal supplied for melting in the production of cast and wrought manufactures. In making ingot the reduction-cell metal from the holding or remelting furnace is poured into iron moulds of the necessary size and shape to yield the required weight and form. A usual form of aluminium ingot is the so-called notched bar. The number of notches may be up to about 13. Ingot without notches is also made. A notch properly considered is the V-shaped de-

pression between the masses of metal which are joined by comparatively thin webs. But in aluminium practice the masses or slugs of metal are commonly referred to as notches. In the case of 10-notch bar, so called, the number of "notches" is 10, and the number of V-shaped depressions is nine. The number of notches or the shape of the bar may denote the nominal composition, especially of alloys. Intermediate alloys or hardeners may be poured into notched ingot molds or made in the form of plaques to facilitate breakage.

Primary aluminium, 99+% grade, is also furnished in several other forms, including ingots for rolling into sheet, bars for the production of rods and wire, slabs, billets and like shapes. Some alloys are available in these forms.

Metallurgical aluminium, 94 to 98% grade, is supplied in the form of notched bars, rolled rods, and granules (shot).

Aluminium ingots for remelting are made in various weights and shapes to meet requirements of the trade. The weight of aluminium ingots or notched bars as produced in the United States may vary from about 1 lb. to 33 lb. And in Europe the weight is from about 200 grms. to 16 kilogs. In American practice the sizes most used weigh one, three, five and 30 lb. In European trade the most common sizes weigh one, two, four, and 15 or 16 kilogs. Little ingots are used for feeding die-casting machines, and are preferred in general where small quantities of metal are to be melted. Big ingots are ordinarily employed for melting in the production of rolling ingots, and also for preparing large lots of alloys in foundries. A common form of metallurgical aluminium sold in the United States is the 1-lb. bar with nine notches. Each small mass joined by the webs weighs approximately 1·6 oz. or about the usual amount added to deoxidize one ton of steel. The bar can be readily severed at the webs.

Considerable quantities of aluminium rolling ingots, wire bars, and other shapes for working have been marketed in Europe, but up to the present time the demand for these products have been small in the United States. In general, the non-integrated American companies engaged in the production of semi-manufactures melt the raw notched metal and pour their own ingots and bars. Rolling ingots and other semi-raw forms are, however, made by most producers of primary aluminium not only for the market, but also, and principally, for their own consumption in processing various manufactures.

Rolling ingots and wire bars in a wide range of sizes are supplied by some European producers. The combined range offered by two producers is as follows: Rectangular rolling ingots, with flat edges, in weights of 12 to 1,000 kilogs.; rolling ingots, bevelled edges, in weights of 37 to 700 kilogs.; square wire bars, with or without one end pointed, weighing eight to 260 kilogs.; and round bars weighing 15 to 320 kilogs. The sizes and weights which are made provide for trade requirements, and have been determined by experience. More detailed information may be obtained from the producers.

The output of primary aluminium is consumed in part by the producers and in part by independent manufacturers of semi-finished and finished goods. As the producers of primary metal have continued to expand in the working-up branches of the industry the market for raw aluminium has contracted. That is to say, the percentage of raw metal output used by the primary producers for their own manufactures has increased. This tendency is likely to become still more pronounced. Apart from the producers, the chief consumers of primary aluminium ingot are rolling mills, foundries, die-casting plants, various manufacturers who operate casting departments, wire mills, and some other makers of semi-finished or finished products. The market for metallurgical aluminium, 94 to 98%, is the raw steel industry.

(*To be continued.*)

Aluminium Production in the British Empire

By Norman L. Brown

ALUMINA, the metallic base of which is aluminium, is one of the most plentiful and widely distributed of all substances in combination with other materials. Only oxygen and silicon are more abundant in the earth's crust. Clays, slates, shales, schists, and the granite rocks are largely composed of compounds of aluminium. The oxides of aluminium include corundum, ruby and sapphire; the hydrates gibsite and bauxite; their compounds with magnesium and beryllium; the sulphates occur in many volcanic districts; whilst in combination with the sulphates of the alkali metals it forms the natural alums. The double fluoride of aluminium and sodium, known as cryolite, is another form in which aluminium is found; whilst the silicates include such diverse materials as the micas, clays, garnets, topaz, and the felspars, etc. Many natural waters contain alumina, sometimes in considerable proportion; whilst it is also found in the ashes of plants.

Unlike most other minerals, aluminium is never found native, and although its compounds are so widely distributed, with few exceptions it is derived from the hydrate bauxite. Vast deposits of this mineral have been located throughout the world, but the main source of this mineral is British Guiana. Originally the ore used to produce aluminium in Great Britain was obtained in Northern Ireland, and although bauxite is still obtained from this source the rapid development in the application of this metal and its alloys necessitated the importation of increasing quantities of bauxite. Vast quantities of other materials rich in aluminium are available, but no economic commercial method of extraction has yet been devised. It is in this direction that progress can effectively be made for the future. Many of the clays, for instance, are rich in the mineral and contain proportionately more aluminium than many of the iron ores now smelted contain iron. Concentrated research on the richest of these materials would ultimately result in their reduction on an economic scale and would have far-reaching influences on the future of the aluminium industry.

Bauxite deposits are generally a considerable distance from smelting plants, and the ore must be transported near to the source of power. In most countries the refining plants for treating the bauxite are, for natural reasons, placed in some intermediate point between the mines and the smelters. Normally, bauxite contains from 55 to 60% of alumina, while high-grade ores, such as those of British Guiana, may contain 61 to 62%. The principal impurities are iron oxide and silica, the percentages present depending upon the grade of the ores. The production of high-purity aluminium is only possible from high-grade raw materials,

and, commercially, it cannot be obtained direct from the ore. Impurities must be removed to leave aluminium oxide as near chemically pure as possible, and this involves somewhat complicated treatment. It is the conversion of the ore to aluminium oxide which makes the process costly. Refined aluminium oxide contains small percentages of the oxides of iron, silicon and titanium, and for high-purity aluminium the commercial aluminium oxide or alumina must be as free as possible from these oxides.

Many other materials are necessary in aluminium production, among which are sodium carbonate and brine for refining the ore, coal, fuel oil or gas for calcining the refined ore; in addition, cryolite, either natural or synthetic, is indispensable in the present commercial production of the metal, as also is carbon for electrodes. The smelting of alumina necessitates a substantial supply of electricity.

The bauxite, direct from mines, is crushed to a suitable size, washed to remove as much earthy matter as possible, and subsequently dried in rotary kilns. Several processes of treating the ore are in industrial operation, but the greater part of the world's production of alumina, especially the bauxites low in silica, is obtained by the Bayer process. In this process the crushed and dried bauxite is treated with a strong solution of caustic soda, under pressure, at a temperature of about 150° C. This causes the aluminium oxide content in the bauxite to pass into solution as soluble sodium aluminate, and is separated from the insoluble contents, comprising principally iron oxide and sodium-aluminium-silicate. The solution of sodium aluminate is diluted and treated with aluminium hydrate, and, by stirring, about two-thirds of the alumina content is precipitated as aluminium hydrate, which is separated from the solution. The solution itself is concentrated and used over again in the treatment of the bauxite. The aluminium hydrate is calcined in a rotary furnace to produce alumina ready for electrolysis.

When the silica content of the bauxite exceeds 5%, the Bayer process is uneconomical, because every pound of silica involves a loss of about 1¼ lb. of alumina, and 2 lb. of soda in the silicate formed. As a rule, ores with less than 3% content of silica are preferred for this process; for those carrying excess of silica the lime-soda process from Le Chatelier's patent, or the more recent Paterson process, may be used.

The reduction of the alumina is effected by electrolysis. The furnace is usually a large rectangular receptacle lined with refractory bricks and carrying an inner lining of an electrically conductive carbon composition forming a hearth on which the alumina is decomposed. Below the carbon lining are cast iron or steel bars which are in contact with the carbon hearths and form the cathode of the operation. Electrolysis takes place at a temperature of about 930° C., at which temperature the melt comprises a solution of alumina in molten cryolite. The anode consists of a number of carbon electrodes in direct contact with the electrolyte.

Under normal conditions the consumption of the different raw materials per 100 lb. of aluminium produced by this process may be taken as approximately 200 lb. of alumina, 60 lb. of carbon anodes, and about 5 lb. to 10 lb. of cryolite. The electric power consumed approximates to 10 k.w.-hours per lb. The raw metal is cast into pig ingots, which are remelted in electric or reverberatory furnaces to remove dissolved gases, sodium and other impurities. In this refining process small percentages of alloying elements may be added according to requirements, and the refined metal or alloy is cast in permanent moulds to form rolling slabs, ingots, wire bars or billets for extrusion.

Great Britain and Canada are the principal producers of aluminium from its ore in the British Empire, although developments are in progress elsewhere in the Empire. In Britain the main producer is the British Aluminium Co., Ltd. Since the early developments by this company in 1894, rapid progress has been made, and since the war the capacity of the various plants has greatly increased. Another, though much smaller producer, in Britain is the Aluminium Corporation.

The production of primary aluminium in Canada is confined to Quebec, in which province the Aluminium Company of Canada, Ltd., operates an ore-treatment plant at Arvida and reduction plants at both Arvida and Shawinigan Falls. Although Canada is rich in minerals which produce, in addition to gold and silver, large quantities of nickel, copper, zinc and lead, no suitable ores have been discovered for the production of aluminium. The main requirements for the production of her primary aluminium are obtained from British Guiana. At Arvida, bauxite is treated by the Bayer process for obtaining aluminium oxide and the cryolite necessary in its reduction is obtained from Greenland.

The plant at Arvida, in the Lake St. John area of Quebec, is one of the largest in the world. The establishment includes, in addition to the smelting plant, a plant for purifying cryolite, an ore-refining plant, and a plant for making carbon electrodes. To handle incoming raw materials and outgoing finished products, terminal facilities are arranged at Port Alfred, 20 miles distant, at the head of deep-sea navigation on the Saguenay River. A railroad connects Arvida with the port and hydro-electric power is developed in large quantities in the district.

The bauxite used is mined by the Demorara Bauxite Co., Ltd. At the British Guiana mines the deposits lie as much as 100 ft. below the surface, and vary in thickness from a few feet to 25 ft. or more. The bauxite is broken by blasting, and after crushing, washing and drying at McKenzie, about 10 miles from the deposits, is shipped direct by ocean-going vessels to Port Alfred, 3,220 miles distant, from which it is transported by rail to Arvida.

Aluminium Casting Alloys and Alloys for Other Purposes

A VERY informative book under the above title has recently been published, the first part of which is concerned mainly with the potentialities of aluminium alloy castings and the outstanding characteristics of the various casting alloys available. Attention is also directed to special alloys of aluminium used in foundries for compounding the commercial casting alloys and to special forms in which aluminium and aluminium containing alloys is supplied for steel additions. General foundry principles are discussed in relation to melting practice, and suitable types of melting furnaces are considered, with special reference to casting temperatures, conditions of melting and fluxes used. The principles governing the preparation of mould are considered, and information is given on the location of gates and risers; possible defects in aluminium alloy castings are discussed, together with their causes, and attention is given to the finishing of castings.

Considerable information is given on the various groups of casting alloys, including the aluminium-copper alloys, the aluminium-silicon alloys, the aluminium-copper-silicon alloys, the aluminium-magnesium alloys, and several individual alloys. Tables are included which give chemical composition of the alloys and also their important characteristics and uses. Attention is directed to particular alloys which have been developed for the casting of electrical equipment and for other special applications.

This book is well produced and excellently illustrated, and contains much useful data on compositions, mechanical and physical properties about Alcoa casting alloys in its 90 pages. It is published by the Aluminium Company of America, Pittsburg, Pennsylvania, U.S.A.

Brookside Metal Company's New Works

Brookside Metal Co., Ltd., Astra Works, Stanmore, Middlesex, aluminium alloy manufacturers, smelters and refiners, have opened new aluminium smelting works situated at "Corville Mill," Park Street, St. Albans.

Future Prospects in the Utilisation of Aluminium

By William Ashcroft

The scope of applications of aluminium ranges from foil for packing to shapes for structural purposes; in regard to diversity of uses, it is unsurpassed by any other metal. At present, conditions have limited its applications, but with careful attention to research and development the well-established uses of aluminium will not only be restored and expanded, but new uses will be developed in the future.

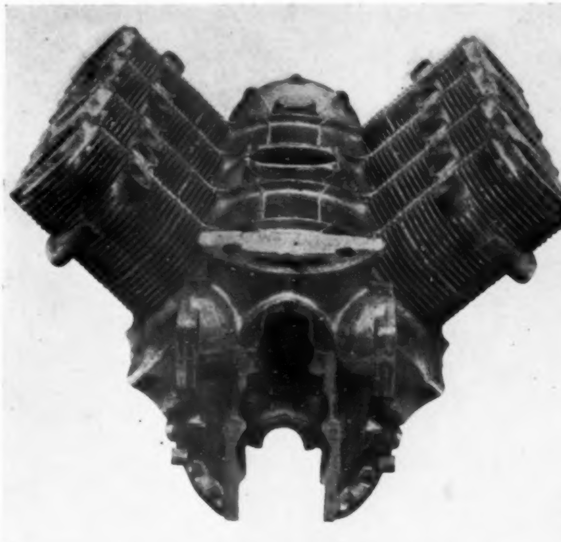
THE exigencies of war have necessitated that the whole of the aluminium produced in this country be applied to war purposes. To meet the increasing demands for metal for these purposes, production of the primary aluminium has been augmented and supplies from overseas have further supplemented home production. In addition, large quantities of secondary aluminium have been released to assist in facilitating the successful prosecution of the war. Thus the industrial application of this metal to peace-time activities has ceased, and it will be necessary for the aluminium industry to plan for a prolonged commercial effort which can be given effect immediately activities cease to be concentrated on the war effort.

It must be remembered that, in addition to increased facilities for the production of aluminium, there has been a great increase in the number of factories for the working and fabricating of aluminium and its alloys, and at the conclusion of hostilities the plant and equipment to be converted to peace-time products will far exceed in capacity the possible pre-war output. Not only is it desirable, therefore, to take all necessary steps likely to restore the applications of this metal to pre-war commercial level, but to effect developments that will result in a considerable advance in its utilisation.

It has not been easy to adjust plant and personnel to war-time needs, and we may be sure that many difficulties will have to be surmounted in returning to the manufacture of peace-time products. The conditions for manufacturing in peace and war are fundamentally different; in the latter control is instituted to ensure that aluminium is available for specific purposes, and producers and fabricators are pressed to supply requirements; in peace-time, on the other hand, it is the work that is to be found to keep the plant and personnel fully engaged and economic aspects have a more important influence. In surveying the future prospects of the aluminium industry, it is assumed that the cost of aluminium or its alloys in comparison with that of other materials will not be overlooked and that a substantial reduction will be effected.

In Great Britain the more important pre-war fields where the use of aluminium showed distinct expansion tendencies were those concerned with transport industries, such as aircraft, motor road vehicles, railway carriages, shipbuilding, etc.; in addition, there was ample evidence of developments in its application for household utensils and equipment, for architectural purposes, industrial machinery, chemical and foodstuffs industries, electrical industries, hospital utensils and equipment, etc.; and there would appear to be no insurmountable reasons against a great impetus to its application in these fields in the future. In many respects progress in some countries is not obstructed by conservative designers and engineers as much as in Britain, and it will be useful to refer to applications elsewhere that are worth considering as possibilities for development in this country.

The importance of lightness of materials used in the manufacture of transport equipment needs no emphasis. It is this characteristic of aluminium, together with other essential properties of its alloys, that led to such a rapid increase in its application in the automobile industry. Probably the bulk of aluminium in pre-war days was consumed by automobile manufacturers, and this will again absorb large tonnages when production is resumed. In the construction of both passenger and goods road transporting vehicles aluminium had been applied to a gradually increasing extent, aided largely by restrictive regulations regarding the unladen weight of motor vehicles. The methods of calculation for taxation purposes make the ratio of high pay-load to low unladen tare of major importance in the construction of motor bodies and the adoption of aluminium alloy construction effects great saving in dead weight. In addition, a vehicle is produced which will stand up to more punishment than the normal steel or wood construction. This field will again consume large quantities of aluminium, and there is scope for considerable development in the construction of motor buses, and goods vehicles of every description.



Courtesy of High Duty Alloys, Ltd.

Pobjoy V-8 cylinder block in Hiduminium RR 50. The cylinder barrels are cast integral with the crankcase. This gives an indication of the progress made in the production of aluminium alloy castings; it is a real "masterpiece" of foundry work.

The remarkable development of aircraft has greatly increased the consumption of aluminium; at the present time it constitutes the largest demand, and the wonderful manner in which war-planes stand up to service conditions speak well for the materials used in their construction. Each single aeroplane utilises a considerable quantity of the metal, varying of course with its size and type, and it is likely that the demand in this field in normal times will continue to be high. It is impossible to indicate the extent of developments in civil aircraft, but so many people are now becoming accustomed to flying and can testify to the

safety of modern planes, that it is safe to assume substantial advances will be made in civil flying. In addition to improved facilities for the air transport of passengers and goods throughout the world, the prospects are quite bright for a great increase in privately owned planes, and the aluminium industry should play an important part in their development.

The application of aluminium and its alloys to the railway rolling stock of Great Britain has not progressed to anything like the degree that is associated with American and Continental railways. This is largely due to the fact that high-speed trains are very popular abroad. These trains are designed to carry the maximum load at maximum speed by means of a given power unit. Since the capacity of the power unit must be kept within defined limits, load and speed are the variable factors to be considered by the designer. Reduction in tare weight is therefore an important feature, as any saving effected in this direction enables an increase in pay-load.

British designers have followed these development with interest, and over a period of years the inherent advantages of light alloys have been appreciated and increasingly applied to rolling stock. Many Diesel railcars operating in this country have their framework and panelling constructed of suitable aluminium alloy, and the tare weight saving effected for each car is over 30%. Several of the main express trains utilise light metals, but by comparison with the railway rolling stock of many other countries the amount used in British construction of this kind is small.

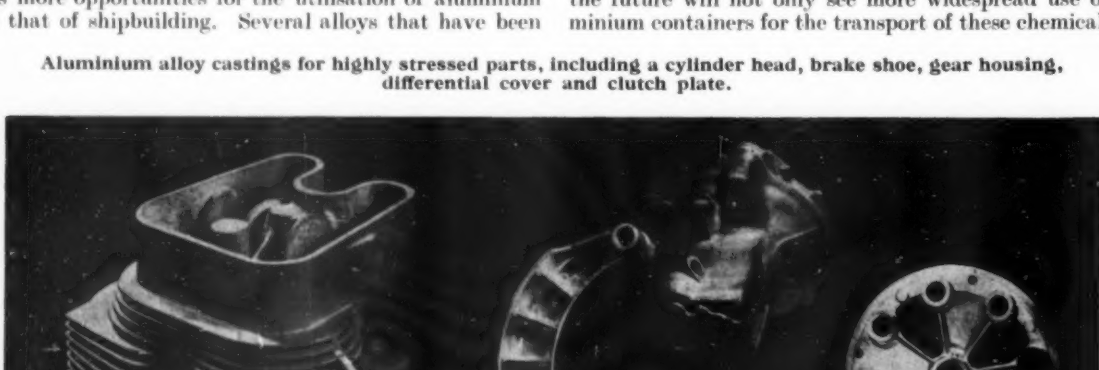
In locomotive construction it is not usually desirable to reduce the total weight of the unit, owing to the corresponding reduction of tractive effort, but reciprocating parts can be made of aluminium, and also such parts as the cab, water-tank, brake cylinders, running boards, fittings, etc.; the weight saved can be exploited in various directions, as, for instance, in increasing boiler and fuel capacity. Greater scope is offered for the use of light alloys in the construction of railway carriages; window frames, panelling, doors, screens, fittings and furniture can largely be constructed of aluminium alloys. Their use for the construction of suburban and underground electric trains is of great importance. In this service especially frequent stops and starts are a severe strain on parts, and by reducing weight this strain is minimised, with a resultant saving in maintenance costs; weight reduction also reduces the consumption of current and increases acceleration and the speed at which services may be run for a given passenger load.

Probably no section of transport equipment industries offers more opportunities for the utilisation of aluminium than that of shipbuilding. Several alloys that have been tested in practice over many years have proved admirably suited to marine applications. Much progress has already been made, and existing light alloy craft are surprisingly numerous. In this country many successful applications of aluminium are referred to by Devereux and Telfer.* The 65 ft. patrol boat *Intercepter*, built in 1933 for the Royal Canadian Mounted Police; the deck-houses of the 120 ft. patrol cruisers *Laurier* and *McDonald*, also built for the Mounted Police in 1936; the 55 ft. express cruiser, *Diana II*; some 22 lifeboats for the Nieuw Amsterdam, 12 for the Awatea, and altogether well over a hundred small boats for all kinds of private, racing, air service and Admiralty use; these are only a few applications of aluminium alloy supplied by the Birmingham Aluminium Co. Various lake vessels have been constructed in aluminium in Switzerland; these include several motor vessels in addition to numerous light craft. In America considerable attention has been given to the use of light alloys in yacht construction.

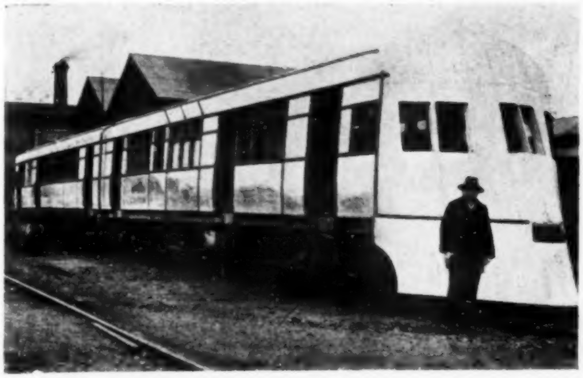
In most maritime countries aluminium is used to a varying extent for internal ship work. Warship applications are, of course, the most obvious and most extensive, and the experience gained with particular alloys is producing a confidence which will ensure their more widespread use. Certainly for fast passenger vessels the weight-saving effected by the use of light alloys will give immediate returns either in increased speed for a similar expenditure or increased carrying capacity for the same power. But in the future fast cargo vessels will inevitably develop, and opportunities for reducing their deadweight will be sought, and the use of aluminium alloys is worthy of the closest examination. Deck plates, hatch covers, airports, grilles, and window sashes are applications on the exterior of large passenger vessels frequently constructed in aluminium alloys; while aluminium furniture, bulkheads, reflectors, numerous fittings, and insulation are widely employed inside vessels.

The lightness, strength, resistance to corrosion and non-inflammability of aluminium alloys make them especially adaptable for containers for transportation of foodstuffs and chemicals. Milk, for instance, is conveniently transported in aluminium containers, and in some countries it is not limited to bulk supply containers, but throughout the whole scheme of transportation from the dairy farm to individual households aluminium containers are used. This material is being increasingly used for containers for transporting such chemicals as acetaldehyde, benzaldehyde, methyl salicylate, paraldehyde, essential oils, acetic acid, acetic anhydride, formaldehyde, butyric anhydride, nitric acid, lacquers, and hydrogen peroxide. It is probable that the future will not only see more widespread use of aluminium containers for the transport of these chemicals, but

Aluminium alloy castings for highly stressed parts, including a cylinder head, brake shoe, gear housing, differential cover and clutch plate.



Courtesy of Northern Aluminium Co. Ltd.



An articulated train in service in China. It is mainly built of aluminium alloys.

that the list will be greatly enlarged, since many other chemicals are known to be unaffected by contact with aluminium.

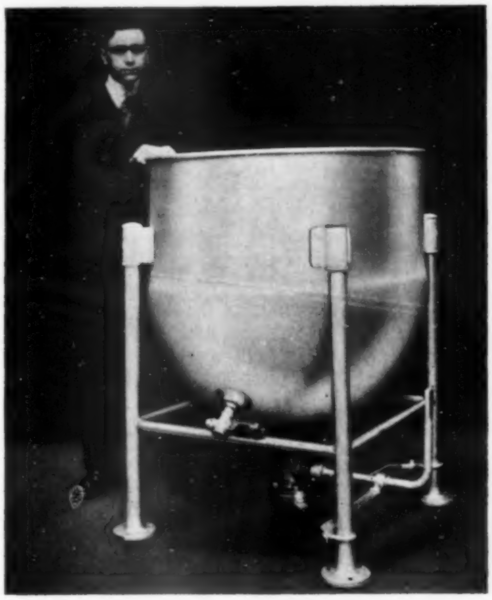
The electrical industry makes use of qualities of aluminium, such as its high electrical conductivity, a good light reflectivity, as well as its resistance to corrosion, strength and lightness. The now familiar steel-reinforced aluminium cables have found wide use in high-tension electric power transmission lines, while aluminium busbars for inside or outside service are much used. There is, however, a growing application of aluminium alloys for outside meter boxes, switch boxes, and control cabinets, while caps to lightning arresters and coupling capacitors in aluminium are now in use. Just prior to the war great progress had been made in developing the reflectivity of aluminium, and there should be an appreciable demand for the metal for outside as well as inside lighting in the future. Aluminium reflectors maintain their high reflectivity for a long time when exposed to adverse weather conditions, thus many applications will be found for them.

The use of aluminium for domestic utensils has long provided a steady market for the metal both at home and overseas, and this application should not be overlooked in a survey of this kind. So many people in this country have sacrificed their aluminium ware to supplement aluminium stocks during this emergency that they will be anxious to restore the brightness of the kitchen, to which aluminium cooking utensils contribute, as soon as conditions permit. Thus for a time at least this field will present opportunities for a considerable tonnage, but will ultimately call for a steady but growing supply of the metal.

The gradual increase in the use of aluminium for architectural purposes before the war was a clear indication of the advantages this metal possesses for such purposes. The natural finish and ease of working aluminium make it particularly suitable for balustrades, decorative panels, handrails, gates, grilles, columns, shop fronts, lamps, and much ornamental work. In addition to its capacity for retaining a surface comparable with silver, it resists corrosion, and it can be given many attractive finishes in a large range of colours and tones.

In the newer buildings erected immediately before the war, decorative work in aluminium was often included, while window sections and sills, as well as considerable exterior fitments, were sometimes introduced. Application was also made of structural members, and doors, gates, etc., were often constructed of cast or wrought aluminium, either uncoated or, usually, given various treatments. At least one building was constructed almost entirely of aluminium, and it is reasonable to expect that in the reconstruction which must take place after the war the demand for aluminium for work of an architectural and decorative character will be on a large scale.

There will be an expanding field of application for aluminium in the brewing industry, where it is used to some



Typical example of aluminium equipment used in the chemical industry.

extent forfermentation and storage tanks. The aluminium beer barrel has made its appearance in the United States, and very satisfactory reports are given regarding them. The reduction in weight for transport is one of the advantages. It is extremely doubtful whether such an innovation will be effected in this country, especially for the transport of beer for home consumption, but there is scope for this form of container for export purposes.

In the canning industry, too, aluminium has been used for some years, more especially in those countries that must import tinplate, which is commonly used for this purpose and which produce aluminium. Many advantages are claimed for the use of aluminium for the canning of certain types of fish. Research by the Norwegian canning industry, for instance, showed that the packing of sardines and kippered herrings in aluminium containers had the following advantages : There was no blackening of the inside of the container ; no metallic smell or taste ; no contamination by injurious metals ; easy opening ; and lighter weight—the normal container in tinplate weighing $3\frac{3}{4}$ oz., whereas the aluminium container weighed 25 grms. Not all conserves can be safely packed in aluminium containers—for instance, investigations have shown that fruit conserves, fish in tomato sauce, unsterilised conserves, and unsweetened milk cannot yet be successful packed in unprotected aluminium containers owing to formation of hydrogen. There is scope in this field, however, for appreciable development. The economic factor is, of course, an important one, and a substantial reduction of the basic price of primary aluminium would be necessary to make its use for this purpose attractive in Great Britain, but it should not be overlooked that the United States, where tinplate is produced in large quantities, has made use of aluminium containers for certain kinds of fish.

Furniture in aluminium was gradually being introduced and a demand can be expected in the future. Hotels, restaurants, theatres, and assembly halls of various kinds will require supplies of chairs, tables, etc., which are satisfactorily produced in aluminium. Much hospital furniture and fitments are made in aluminium ; particular attention may be directed to the use of aluminium food trolleys which are used in a number of hospitals ; the cleanliness and sterile properties of this metal, as well as lightness, are much in its favour.

Minor uses, but which in the aggregate will consume many tons of aluminium, are the wrapping of confectionery,

foods, and various products, which need to be protected against air, moisture or light, in aluminium foil. Heavy foil is used for closures for containers made in glass or other materials, notably for sealing milk bottles. Here again the scope for development is considerable, because the value of this material for a wide range of similar purposes is already appreciated by many manufacturers.

The use of aluminium for moving parts in machinery, especially textile machinery and equipment for wrapping packages, will tend to increase. In many machinery applications speed of operation can be increased without setting up vibration problems that are present when heavier metals are used. The use of the metal is not limited to textile machinery, however, as boot-making machinery, laundry machinery, and many other kinds have aluminium introduced in their construction, while mixing equipment, dough storage tanks, meat slabs, edible oil containers, margarine trucks, ducts and hoppers, are other applications of the metal which will increase future demands.

The high degree of protection afforded by aluminium paint, its clean appearance and high degree of reflectivity, have favoured its use, and although under present conditions it is being restricted to Service applications, it is safe to predict that the merits of this type of paint will lead to increased applications when conditions permit. The paste from which the paint is made consists of granular particles of pure aluminium which are, in some cases, subsequently processed to form flakes. The covering capacity of the paint when made is such as to bring the cost to a reasonable economic figure.

It has only been possible to give a brief summary of many of the applications of aluminium. Scientific research and development have resulted in these applications and have extended its uses to purposes for which it was previously uneconomic in competition with other metals and materials. There will be the same need for research and development in the future to develop new uses and to assist in increasing the demand for well-established applications. With proper co-operation between the producer and user, the future for aluminium is bright and it is expected that demands will greatly increase.

Courtesy of Birmabright Ltd.

Balustrade in polished "Birmabright" to main staircase of the Seaburn Hotel. Designed and executed by Maynsley and Sons, Ltd., for the architects, Messrs. W. and T. R. Milburn, F.F.R.I.B.A.

An Investigation of Some Sources of Inaccuracy which may arise in the Spectrographic Analysis of Aluminium Alloys

A solution method for the spectrographic analysis of alloys has been developed with a view to eliminating inaccuracies that occur in the more usual direct sparking method, and it is claimed that the adoption of suggestions made will immediately result in a considerable increase in the accuracy of spectrographic analysis.

THE spectrographic analysis of steels and certain non-ferrous alloys, such as brasses and bronzes, has been placed on a satisfactory basis, but greater difficulty has been experienced in the case of aluminium alloys. During an investigation, with a view to the development of a solution method for the spectrographic analysis of aluminium alloys, Quarrell and Bramley* encountered a number of sources of inaccuracy which would also be liable to occur in the more usual direct sparking method. The authors summarise the advantages which suggested the development of a solution method for the analysis of aluminium alloys and give a description of the technique which was finally adopted. The method eliminates errors due to segregation and compound formation in the alloys, and also facilitates the addition of an internal standard, as well as the preparation of standard solutions instead of standard alloys.

Two disadvantages of the solution method in comparison with the usual spectrographic method are specially mentioned; one concerns constituents of an alloy which could not be readily estimated, because they are not completely soluble in hydrochloric acid, such as silicon and titanium; the other being the time taken to prepare the solution and in cleaning the electrode. It was therefore appreciated that the solution method was not likely to be useful to industry unless the accuracy attainable was considerably greater than that reached by the more usual spectrographic method. Accordingly, the development of the solution method has been influenced throughout by the desire to eliminate sources of inaccuracy as they become apparent.

After many experiments, it was found that a silver electrode of 99·998% purity fulfilled the necessary requirements. The electrodes were cleaned by boiling 10 mins. in a 60 : 40 A.R. hydrochloric acid, rinsing in distilled water, boiling in distilled water for 10 mins., followed by further rinsing in distilled water and drying in acetone. It was found that the layer of silver chloride left by this treatment was advantageous in that it caused a more uniform distribution and greater adhesion of the residue. After trying many concentrations, it was decided that a salt content corresponding to 0·25 grm. of alloy per 100 c.c. of solution was satisfactory. The desired conditions for the internal standard were best satisfied by the addition of chromium to the final solution. Five drops of this solution were dried out on the lower electrode. Preliminary experiments showed the importance of accurately adjusting the spark gap; for this purpose the upper electrode was fitted into a holder with a micrometer adjustment, and an optical system was used to project a magnified image of the spark gap to facilitate its setting.

The spectra of two complete series of ten solutions were recorded on each photographic plate. It was frequently found that when log ratios were plotted against concentration in the normal manner, the results from one half of the plate fell reasonably well on a smooth curve, while those from the other were, by comparison, most unsatisfactory. It was found that these were due to stress marks due to pressure exerted on the emulsion when the plate was being removed from the box. The effect of these stress marks upon the accuracy of spectrographic analysis is relatively unimportant, since any estimation based upon sensitive lines which coincided with stress marks would naturally be disregarded, but this would necessitate the repetition of the analysis; it is therefore undesirable to use an emulsion which is liable to stress marking.

Experiments carried out to determine the most suitable emulsion for spectrographic purposes have shown that more consistent results should be obtained by developing the plate for a longer time than is usual. Further, it has been shown that the extent of the straight-line section of the characteristic is very limited when converted to photometer deflections. As a result, the log-ratio method can only afford approximate compensation for variations in conditions of excitation. If, instead of the log ratio, the difference in photometer deflection between the internal standard and unknown alloy is plotted, satisfactory compensation can be achieved over a larger range of photometer deflections and with a simplification of the calculation necessary.

The fact that the limited extent of the straight-line part of the characteristic does not seem to have been noticed before leads to the suggestion that it would be well worth while determining the characteristic of each plate used, with a mercury lamp as standard source of illumination. The method of interpretation suggested would reduce the number of curves which need be drawn for each plate to one—that is, the characteristic—and would have the added advantage that it should be possible to take advantage of previous experience in a systematic manner to increase the accuracy of subsequent analyses. This is because the value of log I_1/I_2 is characteristic of the composition of the alloy alone, whereas the value of the log ratio normally used is determined by both the composition and the photographic plate.

The authors outline the theory upon which the spectrographic side of spectrochemical analysis is based, and state the following requirements which photographic plates should fulfil for this purpose :—

(1) The straight-line portion of the characteristic should be as extensive as possible.

(2) The emulsion should have maximum contrast—i.e., γ should be as large as possible, so that d_2/d_1 is large.

(3) In order to minimise errors in using the microphotometer, the emulsion should be fine-grained.

(4) The emulsion should not be subject to stress-marks. The processing technique adopted should be such as will lead to the smallest variations in γ between different plates and should give maximum contrast.

The time of development should be long enough to ensure that any small changes in it should not cause appreciable changes in γ. The use of an intermediate stopping bath is recommended, as it makes the action of stopping more certain.

Attempts to obtain characteristic curves for different emulsions for the ultra-violet end of the spectrum were made with iron spark and arc illumination, but it was found that neither could be kept sufficiently constant. Finally the use of a high-pressure mercury discharge lamp enabled, the characteristic curve to be evaluated in the region 3,500–2,900 A. Photometer readings converted to density readings by the ordinary log-ratio method, showed that in the best of the emulsions used the extent of the straight-line region (in terms of photometer deflections—full-scale =

* A. G. Quarrell and G. E. A. Bramley. *Jour. Inst. Met.*, Jan., 1941, **67**, Part 1, pp. 25–47.

50 cm.) was only 17 cm. Therefore, using the ordinary log-ratio method, accurate results cannot be expected if the photometer reading corresponding to either internal standard or unknown element line is greater than 17 cm.

It is suggested that in the circumstances it is preferable to obtain standard curves for the analysis of alloys by plotting difference in photometer deflection against concentration. This method would enable more of the photometer scale to be used with accuracy, it would simplify calculations, and make any drift in the galvanometer zero unimportant.

The authors do not claim that the adoption of any or all of the suggestions made in their report will immediately result in a considerable increase in the accuracy of all spectrographic analyses. It is well known, however, that whilst perhaps 90% of the results at present obtained are accurate to within about ± 5% of the amount being estimated, the remaining 10% of the estimations may be considerably in error. Attention to the points enumerated above should definitely effect some improvement in this respect, and the adoption of the method of interpretation finally recommended will simplify the technique and place the spectrographic analysis of alloys upon a more fundamentally sound basis.

The Pressing of Metal Powders

METHODS of compressing metal powders have progressed greatly during the last few years, and today many complicated shapes can be pressed that formerly were considered impossible. The future of powder metallurgy rests largely upon a study of the fundamentals covering the compression of metal powders, and this aspect of metallurgical practice has been dealt with recently by R. P. Sellig* in a manner which tells the engineer, who has to design the die and supervise the pressing operation, how such things as the behaviour of powder particles as individuals or in the mass, die-filling, ejection of the pressed compact, press capacity, lubrication, die-setting, etc., should be done.

Phenomena observed in the compression test with solid metals seem to play a part in the compression of metal powders, and each powder particle may be considered an individual compression test specimen, but of irregular shape. When considering the whole mass of powder particles, however, the solid metal is not dealt with in the ordinary sense, and the phenomena displayed in compressing powders can be said to occur in an intermediate state between the liquid and solid, due to flowing and other compression characteristics. As the metal is confined in a die on all sides, the stress distribution is different from what occurs in the standard compression test and pressure cones which are noted in this test do not develop. Since the pressure acts on all sides, the pressure in the die resembles a liquid in a vessel under pressure, but the comparison with the liquid state does not hold true when it is considered that one of the most important phenomena in metal powder compression is that pressure is not evenly distributed, part being absorbed by internal friction in the metal powder and part by friction of the powder with the die walls. The behaviour of metal powder under pressure is found to be complicated by the fact that a great number of small particles, which lack any metallic bond except that produced by the pressure, are closely packed and are in a state of cold deformation. There is no evidence to show that there is a preferred crystal orientation in compressed powders, and during the latter stage of compression the material approaches more and more the state of a polycrystalline mass held together by the action of pressure, friction and adhesion. Porosity should be avoided and close contact between particles attained so as not only to facilitate subsequent sintering operations, but also to increase the strength of a compact in the as-pressed state.

Compression is rendered difficult if the powder is in a cold-worked state, and that s why powders of the same metal, but manufactured in different ways, can be fundamentally different so far as their pressing properties are concerned. Friction between particles also occurs, and this, together with surface films produced by oxidation, may be an important factor in subsequent sintering operations. Not only the amount of pressure, but also the rate of application of the load are factors which must be considered especially with powders which have undergone little or no work-hardening. As regards shape, powder particles are not necessarily of a spherical nature, being more or less irregular, and as such are preferred, where high density and strength are desired in the compressed compact.

The main problem of the pressing operation is that it is necessary to fill the die, on the average, with about three times as much material by volume as the desired shape, and this factor is responsible for some limitations of the powder metallurgy process. Metal powders do not act like either liquids or plastic materials, so that when filling a die it must be visualised that powder will not flow around corners or fill out intricate shapes, and special devices have to be devised to eliminate part of this difficulty. For production work the compressed piece must be removed from the die automatically, and for this reason the best die design requires that the largest cross-section of the die is on the side towards which the piece is being ejected. The straight line pushing of a compact out of the die requires considerable pressure and usually a long stroke depending upon the size and shape of the part.

Any press may be used for the compression of metal powders provided that there is considerable filling space for relatively long parts, and that the press has a good-sized ram and ejector. High pressures are in most cases required where high density and strength are important, and where large cross-sections are involved, a high-capacity press must be selected. In many cases the capacity of the available press equipment constitutes a limitation of the parts that may be handled. The material and wall thickness of presses have to be such as to withstand high pressure, which range in commercial practice from 20 to 100 tons per sq. in. Die walls are usually smooth, so as to facilitate ejection and for some purposes a taper is provided if the tolerances allow, the amount of taper being based on experience with each particular product. A taper avoids excessive friction, sticking of particles to walls, roughening of the surface, and lamination. In order to overcome the same difficulties, a lubricant is often applied to the die. Such a lubricant cannot be an oily substance, because it would penetrate the porous metal compact and would leave carbonaceous residues upon heat-treatment. Soapy lubricants suspended in solvents which volatilise even before the powder is filled into the die have given satisfaction.

The technique of setting a powder metallurgy die into the press is not very much different from ordinary die-setting, and once the die is set the operation begins with the feeding of powder into the die, and this may be done by hand or automatically. During the pressing operation, the punch moves into the die, and the press is released either when the desired pressure is reached or when the ram has travelled a predetermined distance. When this stage is attained, the ejector throws the compact out of the die. In the pressing operating, an important factor is the speed of pressing, and this depends to a large extent upon the type of powder used, lubrication, and size and shape of part to be pressed.

The compact resulting from the pressing operation may have considerable strength and hardness, especially if it is composed of one of the ductile metals, and severe stress or, more particularly, shock will break such a piece. In all cases where strength is a factor in the finished part a subsequent heat-treating operation is applied. The most universal practice in powder metallurgy consists, therefore, of cold pressure and subsequent sintering. In some cases a second pressing operation is used after sintering.

1 *Metals and Alloys*, 1940, vol. 12, No. 6, pp. 744–748.

Billet-Heating Furnace Developments

Control of Reheating Effects Marked Improvement in Finished Products

Uniformity of temperature of the heated billet, the furnace atmosphere, and facilities for conveying billets through furnaces, are factors which have been given particular consideration in the design of recent furnace installations. Some typical examples of billet-heating furnaces designed to conform with metallurgical advances indicate the progress achieved. They are designed to meet the increasing demand for improved quality of the finished product.

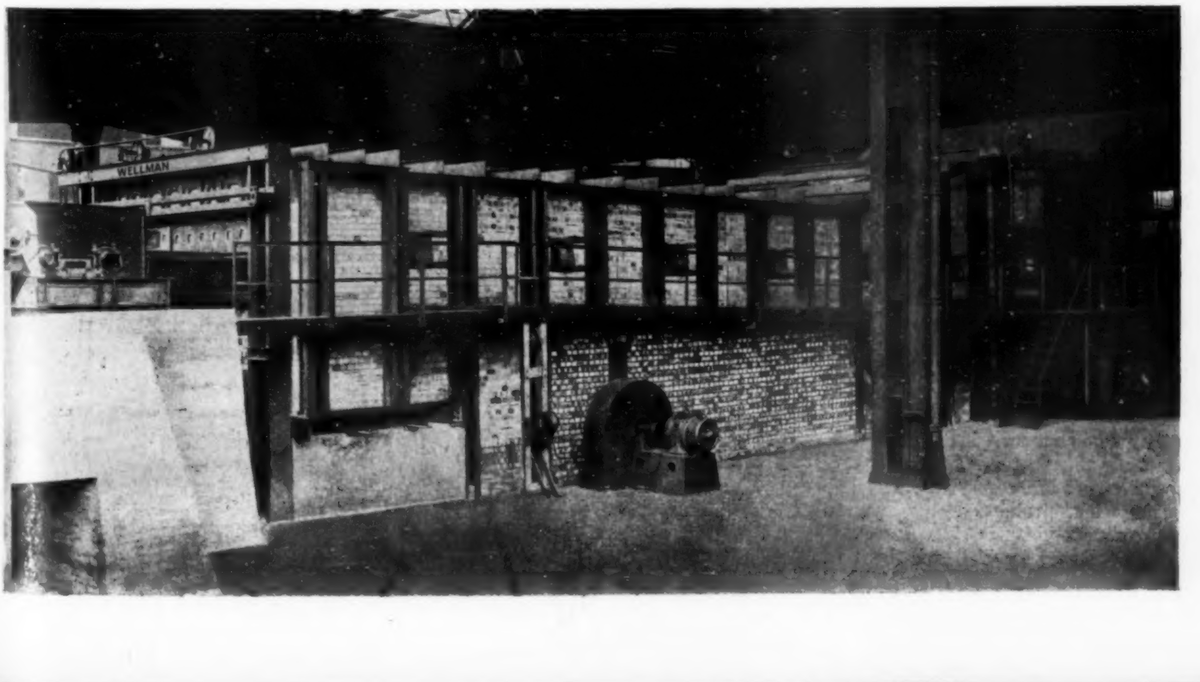
Incandescent coal-fired continuous shell billet heat furnace.

THE reheating of billets for subsequent processing is frequently regarded too lightly, with the result that difficulties arise, due to lack of uniformity of the material. The irregularities which are thus encountered in the finished product are not always thoroughly investigated, and yet, in many cases, they could be eliminated by a better control of the heating operation to which the billets are subjected. The rate of heating is of considerable importance and is dependent upon the size, shape, and composition of the billets to be processed, and also upon the work to be done. With steels the correct heating temperature is usually governed by the carbon content ; this applies also to alloy steels, although in some cases the physical effects on the steel by its alloy content results in exceptions. Whether ferrous or non-ferrous billets are required to be heated, however, investigations have shown that marked improvement in the finished products has been effected by improved methods and heating equipment, and in recent years progress in the design of billet-heating furnaces has been considerable.

The ever-increasing demand for better quality of the finished product has gradually emphasised the importance of reheating in so many operations and has caused attention to be directed to the design and operation of billet-heating furnaces. Two of the factors which have resulted in irregularities are variations in the temperature of billets being processed and lack of temperature uniformity of individual billets. There has been a tendency to overheat the outside of the billet and a failure to regard the temperature of the inside as the main factor in determining the physical properties of the material in its finished condition. It is now more fully recognised that heating furnaces require to be designed and operated on a standard comparable with modern heat-treatment furnaces, and, in consequence, modifications have been made which are successfully contributing to the present need for improved quality of products processed from billets. Economy in fuel is still one of the dominant factors in design, but of greater importance is the need for uniformity of temperature of the billet, and it is mainly to this end that refinements have been incorporated in designs of billet-heating furnaces.

Fig. 1.—Continuous billet-heating furnace designed for an output of 20-25 tons per hour when heating 6 in. steel billets 12 ft. long.

Courtesy of the Wellman Smith Owen Engineering Corporation, Ltd.



For many purposes, such as the piercing of steel billets and the extrusion of nonferrous billets, a very even heat is essential, allowing practically no temperature differential through the body of the stock. Apart from the uniformity of temperature, the question of furnace atmosphere, and also facilities for conveying billets through the furnaces, are other factors which have been given particular attention, and some examples of recent furnace installations indicate the degree of progress achieved in providing billet-heating furnaces designed to conform with advances in metallurgical knowledge and at the same time maintaining economy of operation.

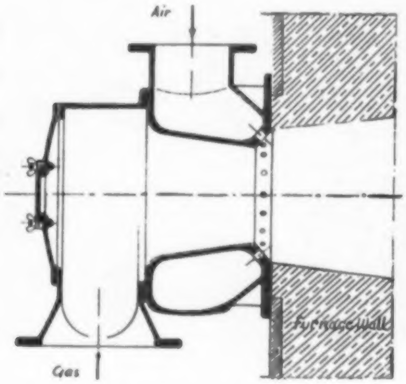
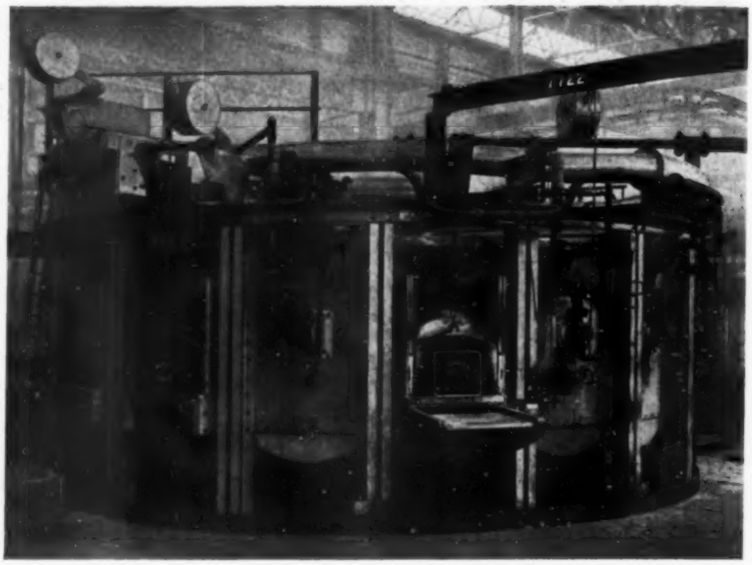


Fig. 2.—Sectional drawing of the "Basequip K" patent gas burner.



Courtesy of the Wellman Smith Owen Engineering Corporation, Ltd.

Fig. 3.—Rotary hearth reheating furnace, with a hearth of 14 ft. mean diameter, and designed for an output of 3 tons of steel billets per hour.

Great improvements have been made in the familiar continuous-reheating furnaces, particularly as regards the application of heat. An interesting example of this type is the furnace illustrated in Fig. 1, which is probably the largest continuous billet-heating furnace in Great Britain. It is designed for an output of 20 to 25 tons per hour when heating 6 in. billets 12 ft. long. The furnace has two fire zones, one above the stock and one below, and the billets are pushed down on two sets of water-cooled skids. It is fitted with a special suspended roof, and is arranged for firing with producer gas, or mixed gas. The pusher is of the double cross-head type, which can be arranged to push either one single row of 12 ft. lengths of two rows of 6 ft. billets.

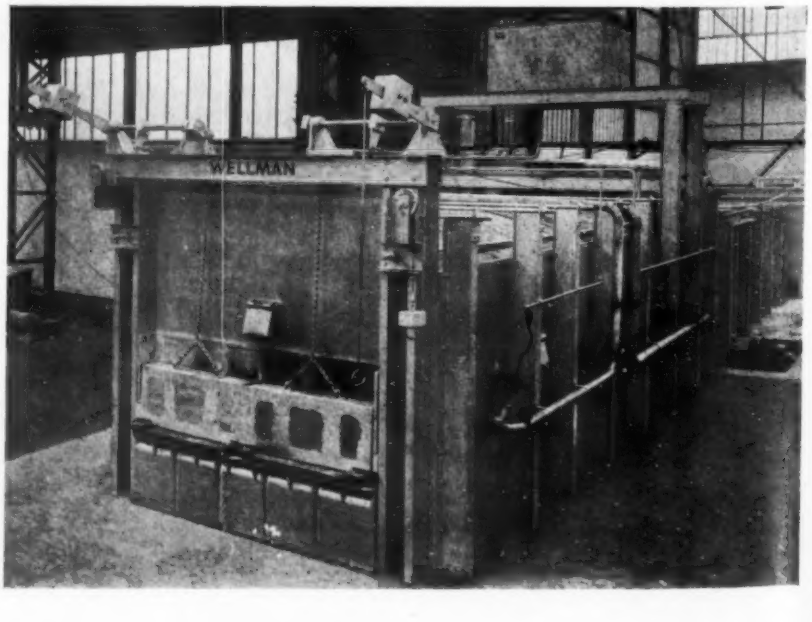
Ordinary port type furnaces are still being built for steel mills, but when large outputs are required or when increased control of the temperature and rate of heating becomes necessary, metallic burners placed in the end and side walls of the furnace are finding increasing favour. A number of furnaces of this type have been installed by the Wellman Smith Owen Engineering Corporation, which are claimed to give a perfect control of heating conditions over the whole area of the hearth and assure a constant supply of homogeneously heated material for the mill. This firm preferably use for this purpose the "Basequip K" low-pressure gas burner, which will handle any type of industrial gas, including hot raw producer gas, and will also work with preheated air up to approximately 400° C.

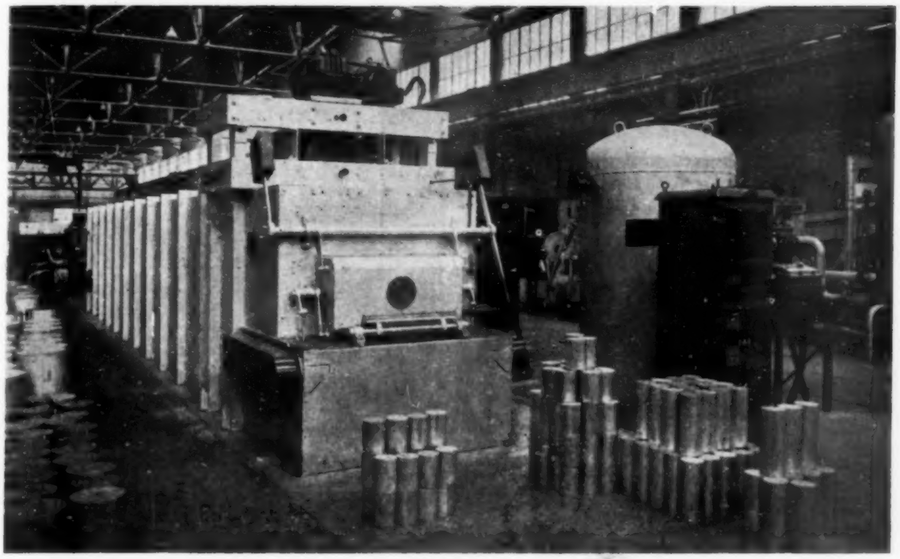
The "Basequip K" gas burner, a sectional drawing of which is shown in Fig. 2, is designed to give instantaneous and complete combustion of all gases whether clean or dirty and tarry. The sectional drawing shows the orifice for entry of gas surrounded by a number of small holes through which the air enters. These holes are drilled tangentially and give a rotary motion to the mixture of gas and air, thus ensuring thorough mixing and immediate combustion. The gas enters at very low velocity and the air at a pressure of between 4 in. and 6 in. water gauge. These burners give control of the working temperature and furnace conditions can be fixed at will. When working with a neutral or reducing atmosphere, the fact that there is no free oxygen is of importance.

To meet the conditions required for such purposes as the piercing of steel billets, the "Wellman" rotary hearth furnace has been developed, and a number of successful installations have been made. In this furnace the stock to be heated is placed on a circular hearth which rotates

Fig. 4.—Continuous reheating furnace for copper billets fired by oil fuel. Combustion takes place in a muffle.

Courtesy of the Wellman Smith Owen Engineering Corporation, Ltd.





Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 5.—Conveyer type furnace for preheating aluminium alloy billets prior to extrusion. The chamber dimensions are 34 ft. long, 2 ft. 9 in. wide, and 12 in. high; it is electrically heated.

within the furnace, and by this method the individual pieces may be spaced well apart, so that heating is effected over three sides. The furnace shown in Fig. 3 is of this type. It is fired with coke-oven gas through "Basequip K" burners, and using preheated air. The method of heating and the arrangement of the billets ensures even heating. In this instance, the billets pass into a piercing press, where the benefit of the even heat is shown by lack of eccentricity in the finished product. The furnace is charged through the door on the extreme left of the illustration and discharged from the door in the foreground, thus the billets have a path of approximately three-quarters of the complete circle. The hearth of this furnace has a mean diameter of 14 ft., and is designed for an output of about 3 tons per hour.

A large rotary hearth furnace of the above type is used for heating billets for seamless tube manufacture. The mean diameter of the hearth is 30 ft., and its output is approximately 10 tons per hour. In this case the furnace is fired with mixed gas supplied at sufficient pressure for self-aspirating burners. It has proved highly efficient in operation, and shortly after its installation repeat orders were placed for two further furnaces of the same design. The furnace is charged by a specially designed charging machine, but is discharged by hand. It is so designed that the direction of rotation can be reversed for discharging the furnace in an emergency.

The processing of non-ferrous metals has been remarkably improved during recent years, and considerable attention has been given to the design of reheating furnaces for heating copper billets. A typical continuous reheating furnace for this purpose is shown in Fig. 4; it is fired with oil from a series of burners placed along the furnace sides. Combustion takes place in a muffle, which keeps the gases away from the stock, but the muffle only extends over the distance where combustion actually takes place and, at the colder part of the furnace, towards the charging end the waste gases are actually in contact with the billets. The copper billets or slabs to be heated are stacked in front of the charging door, the bottom slab being pushed into the furnace by an automatic pusher. A special auxiliary long-stroke pusher allows the furnace to be emptied whilst under heat.

It is in the extrusion of non-ferrous metals, however, that probably the greater improvement is manifest. A great variety of materials can now be produced in all kinds of sections, both open and closed. In particular the production of extruded aluminium and light metal alloys has been increasing in a wide field. The importance of uniformity of temperature for this operation must be emphasised, but the temperature of the billet at which extrusion is best carried out is also or vital importance. Variations in temperature will depend on the composition of the alloy, but brass billets may be heated up to 850° C. and alumiuium alloy billets up to 500° C.

In some cases difficulties encountered in the extrusion of aluminium alloys have been overcome by the introduction of electric heating furnaces, because of the high degree of control of temperature which can be effected. A typical example of a conveyer-type furnace installed for heating aluminium alloy billets prior to extrusion is shown in Fig. 5. The chamber dimensions are 34 ft. long, 2 ft. 9 in. wide, and 12 in. high, and the equipment is rated at 115 k.w. in three separately controlled zones. Rapid heating and temperature uniformity is obtained by the provision of a high velocity centrifugal fan mounted on the roof of the charging end; the air stream being controlled by baffle plates. Various sizes of billets can be handled, and a selector mechanism at the delivery end enables full, half, or one-third length billets to be discharged at will.

Probably the most interesting furnace of this type is the billet-heating furnace installed to serve one of the largest

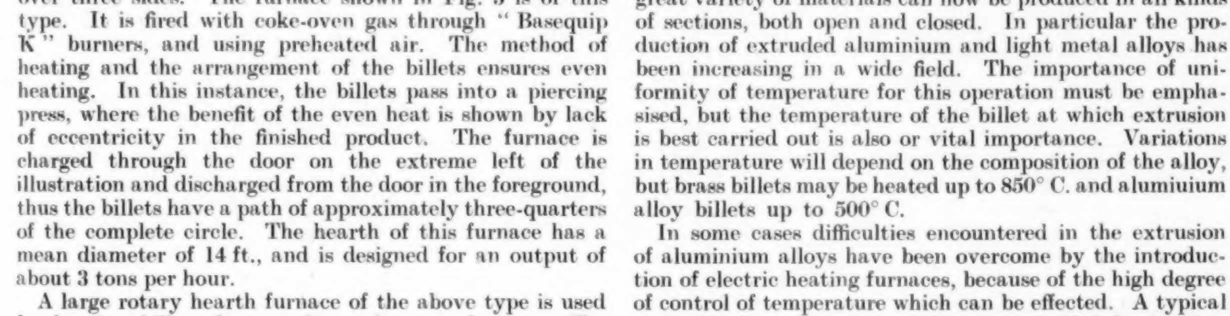
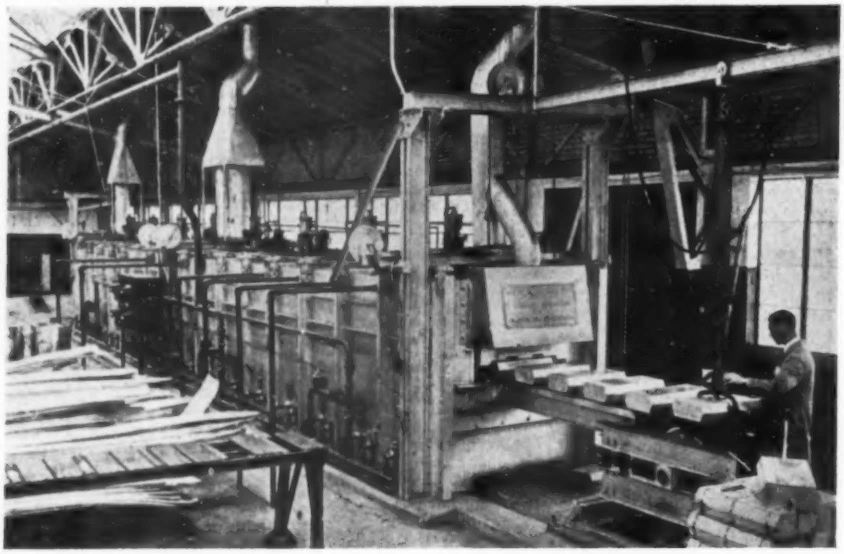


Fig. 6.—Automatic conveyer furnace for preheating aluminium alloy billets 20 in. diameter and 48 in. long for extrusion. Two rows of billets are automatically charged, and the furnace has an output of 3 tons per hour.



Courtesy of Incandescent Heat Co., Ltd.

Fig. 7.—Town's gas-fired continuous furnace for heating aluminium alloy billets prior to hot rolling operations. The heating chamber is 55 ft. long, 3 ft. wide, and 1 ft. 4 in. high, and has an output of 2,550 lb. per hour.

hydraulic extrusion presses ever built. Designed for the production of sections up to 60 ft. long, this press will extrude aluminium alloy billets 20 in. diameter and 48 in. long, each weighing approximately 1,600 lb. The furnace for heating these billets was designed specially for the work, and the Gibbons-Marchant drive has been incorporated into what is an entirely automatic conveying system by which the billets are picked up from the floor level at one end and delivered to the press-feeding mechanism at the other end of the furnace.

This furnace is designed to have an output of 3 tons of aluminium billets per hour at a temperature of 450° C. The rating is 600 kw., and the length of the heating chamber approximately 40 ft., comprising two parallel rows of billets operated by four main pusher rods under the Gibbons-Marchant system, with a joint device on the charging end. Side doors are not necessary, because there is no danger of the billets being jammed when rolling towards the leading rails on the sides, as the billets are forced forward individually by the driving arms on both ends. The billets are raised from the shop floor and charged automatically as shown in Fig. 6. Each row of billets is provided with a separate release mechanism, comprising a tilting cradle inside the chamber interlocked with the door-opening device.

The main advantage of the system incorporated in this furnace is the simplicity of the heating chamber, the size of which is only a little in excess of the useful cross-section—i.e., by the space for the driving rods under the billets. The furnace obviates the additional heat losses caused by the drum shafts passing through the walls of the heating chamber, and by the channels for the returning chains as are necessary in the usual type of conveyer furnace. The fact that the billets roll on the hearth greatly adds to the accuracy of heating to the closest possible limits and the amount of energy required, for conveying is very small, without any danger of sticking or jamming, as the billets are driven individually through the chamber.

In addition to heating furnaces for extrusion billets, considerable developments have been made in the heating of aluminium alloy billets for rolling operations. Here again temperature is an important factor. From the production point of view, a high temperature—below the critical hot-shortness temperature corresponding to the maximum draft—is advantageous because the passing may be more drastic—i.e., the operation may be carried out faster. On the other hand, certain operating difficulties are concurrent with high rolling temperatures. Thus, it is more troublesome to hold dimensions precisely with increasing temperatures, and the billets are prone to be fire-cracked when passing at higher temperatures. However, though the temperature of the billets for rolling may vary according to requirements, it is important that it should be uniform throughout the billet.

A large number of furnaces have been installed in recent years which have been specially designed to meet the requirements of hot rolling operations of aluminium alloys, and the town's gas-fired continuous furnace shown in Fig. 7 can be regarded as a typical example. This furnace has internal chamber dimensions 55 ft. long, 3 ft. wide, and 1 ft. 4 in. high to crown of arch, and has an output of 2,550 lb. per hour. It is fired by a series of incandescent self-intensifying gas burners situated a considerable distance below the conveyer. Heating of the billets is effected by high velocity connection currents, with positive circulation and recirculation of atmosphere through the supporting hearth. This positive recirculation has the important effect of creating high turbulence, thus eliminating stagnant pockets—and inherent disadvantages of paddle-fan practice. When working under continuous discharge conditions, temperature uniformity can be automatically controlled within 3·5° C. in this furnace.

Precipitation in Copper-Beryllium Alloys*

THE changes in atomic configuration which take place during the breakdown of a supersaturated solid solution affect many of the physical properties of the material. Suitably controlled, such changes have been used to enhance the mechanical properties in a large number of alloys—viz., the so-called age-hardening alloys.[1]

A preliminary survey[2] has been made of the thermal effects accompanying the age-hardening process in five typical age-hardening alloys. The results obtained indicated that more detailed examination, using sensitive thermal methods, would provide experimental data that might be of value in improving present knowledge of the mechanism of the breakdown of solid solutions.

The present paper records the results obtained from an examination of the thermal effects observed during the precipitation of the γ phase from a copper-beryllium alloy containing 2·6% beryllium by weight. The thermal measurements have been supplemented by hardness measurements and X-ray photographs. The experimental results are discussed in connection with the theory of nucleus formation as developed by Becker.[3, 4, 5]

Obituary

We regret to record the death, at his residence, Hosie House, Hosie Croft, Westerham, Kent, of Mr. T. U. Hill, who, until he retired in 1935, occupied the position of London manager of the Carborundum Co., Ltd., Trafford Park, Manchester. Mr. Hill joined the company in 1907 and took a leading part in the development of the abrasive industry in this country.

* F. W. Jones and P. Leech. *Jour. Inst. Met.*, Jan., 1941, Part 1, **67**, pp. 9–24.
1 P. D. Mercia, *Trans. Amer. Inst. Min. Met. Eng.*, 1932, **99**, 13–54.
2 N. Swindells and C. Sykes. *Proc. Roy. Soc.*, 1938 (A), **168**, 237–263.
3 R. Becker. *Z. Metallkunde*, 1937, **29**, 245–249.
4 R. Becker. *Ann. Physik*, 1938, (v), **32**, 128–140.
5 R. Becker. *Proc. Phys. Soc.*, 1940, **52**, 71–76.

Flame Hardening Equipment

Cost, convenience and serviceability are the main factors in determining the process selected to surface-harden metal parts to increase their resistance to wear. The application of flame hardening has greatly increased in recent years, and developments in equipment for effecting this process have contributed to the progress. Developments of the Shorter process are described.

WHEN a metal is surface hardened, the outside is made resistant to wear, while the inside retains the toughness and resistance to shock and impact of the original metal. There are a number of surface hardening processes and cost, convenience and serviceability are the main factors in determining the process chosen. For many purposes the flame-hardened process possesses outstanding advantages. In this process the surface is heated by an oxy-acetylene flame immediately followed by a suitable quench. The process is flexible, gives effective quenching, no change in the chemical composition of the hardened surface results, it is speedy in operation, gives good surfaces characteristics, and the hardened surfaces are free from scale. The process is applicable to carbon steels containing approximately 0·30 to 0·60% carbon, to low or medium alloy steels, and also to certain cast irons. There has been increased interest and appreciation of the value of flame hardening during recent years, and developments in the equipment used have greatly encouraged the application of the Shorter surface-hardening process. With increasing experience in the use of this process, machines have been improved and new designs developed to widen its scope, and reference to some of these developments will be of interest.

It is convenient to classify machines for surface-hardening according to the method by which the necessary relative movement is obtained between burner, quench and work. In this way the machines can be arranged in four classes: (1) Machines in which the work is stationary, and the burner moves over the surface to be treated, followed more or less closely by a quenching jet or jets; this is the original "Shorter" machine for which the following machines have been developed. (2) Machines in which the burner and quench are stationary, and the work moves past them, in order to produce the same relative motion as in the previous machine. (3) Machines in which the burner and quench move in one direction—e.g., longitudinally—and the work simultaneously moves in another direction—e.g., rotates. (4) Machines in which the burner is applied first to a rapidly rotating workpiece, and then the burner is removed and a quench brought into action.

Many types of Shorter surface-hardening machines are now available. For hardening spur, bevel, single and double helical gears, and for all straight surfaces within the capacity of the machine, either of types G 1 and G 2 may be used. The former is complete with motor and gearbox and with rheostat spring-loaded lever control from saw-tooth clutch for instantaneous starting and stopping. The latter is a new design, and the carriage carrying the machine head is driven by a motor through a saw-clutch chain and sprocket mechanism, worked in conjunction with a Ward-Leonard set power unit for infinite gradation control. The auxiliary clutch mechanism is incorporated to drive an independent secondary shaft, for use in conjunction with a head and tail stock suitable for treating work of a cylindrical shape, such as worms.

The set-up of the Shorter G 2 machines for the treatment of two treads of a track shoe is shown in Fig. 1. The shoes, which are of forged or cast steel, are held in a jig having provision for mounting two components. Two special water-cooled burners with integral quench are adjustably supported on the machine head. The area to be treated is controlled by an automatic gas valve tripping mechanism situated at the rear of the machine head. As the tread width is irregular, so must the burner flame width vary, and this is accomplished by the trip mechanism referred to. One of these forgings is fully treated in 3–4 mins., and the area hardened is approximately 30 sq. in.

The same machine equipped for the surface hardening of alloy steel driving claws is shown in Fig. 2. In this case it was decided to mount the component in a jig, so that the axis to be treated could be brought parallel with the direction of traverse of the machine head and burner. The jig is of fabricated construction, and is supported on the outside framework. A specially formed water-cooled multi-jet copper burner is used in tandem, with separate quenching tubes, and are placed back to back for suitable indexing by the stops, on the cross carriage. Although there are four

Fig. 1.—The Shorter G 2 machine set up for the surface hardening of two treads of a track shoe.

Courtesy of Shorter Process Co., Ltd.

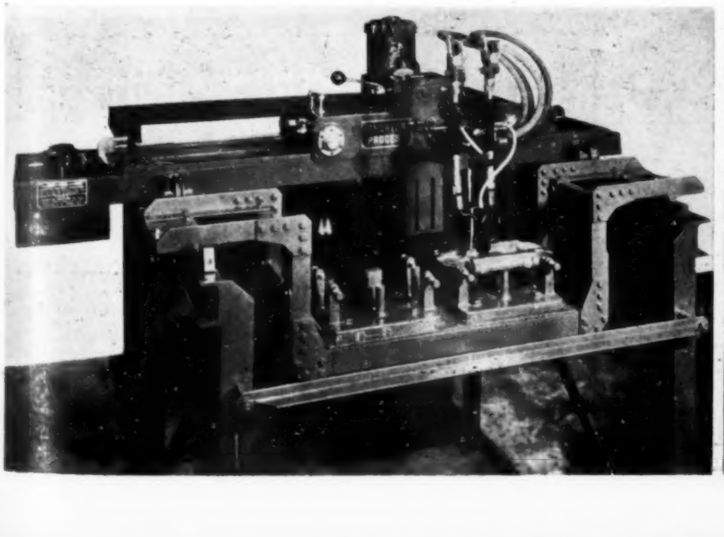
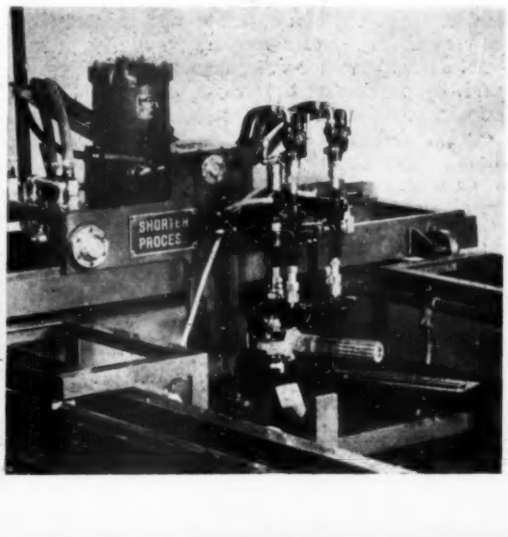
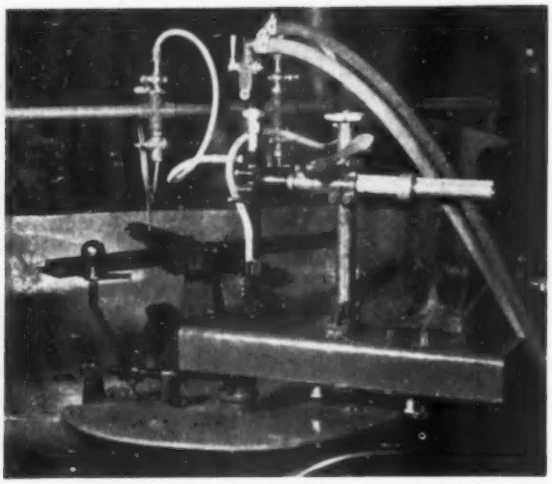


Fig. 2.—Equipment of a G 2 machine for surface hardening alloy steel driving claws.

Courtesy of Shorter Process Co., Ltd.





Courtesy of Shorter Process Co., Ltd.

Fig. 3.—Equipment of the J 1 machine adapted for hardening irregular shaped surfaces.

faces to be treated on each claw, having a total area of about 12 sq. in., between 30 and 40 of these parts can be surface hardened by this machine in an hour.

Another machine built on the lines of the G 2 machine, except for the supporting frame, tank and work-holding pedestal, is the G 3 machine, which is designed for the multiple hardening of small details, shear blades, slides, and straight edges. A light type straight-line surface-hardening machine, G 4, is designed for treating small components. For surface hardening of machine-tool slides, beds, straight edges, and all straight surfaces, is another modified form of the G 2 machine, known as the E 1 machine. Because of wide differences in the capacity, this machine is usually built to suit specific requirements. For hardening sprocket profiles, edges of templets and similar articles of irregular shape, the K 1 machine has been designed. In this case the work-piece is located and indexed to work with a projecting templet, and angular and vertical adjustments for control are provided.

For the profile hardening of sprocket teeth and other irregular shaped surfaces, the J 1 machine has been developed. This machine comprises a work-carrying turntable to index sprockets under treatment. The flame equipment is mounted horizontally upon a slide, one end of which is equipped with a tracer roller in contact with a templet specially developed to describe the required path of the flame for the treatment of sprocket teeth. The essential parts of this machine are shown in Fig. 3. Apart from sprocket teeth, this machine is readily adapted for the surface hardening of many irregular shaped jobs.

The main object of surface hardening is, of course, to reduce the wear of a working part of a machine that is subjected to greater wear than the balance of the machine and, by prolonging the life of this part, the maintenance repairs to the whole machine are lower and it gives longer service. The machines referred to for the flame surface-hardening process are finished to machine tool standards to ensure accurate control of heating and quenching, and the results obtained have greatly extended its application.

Import Licensing of Chemicals

The Open General Licence applicable to chemicals liable to Key Industry Duty has been revoked, and all chemicals to which it applied will now require separate licences unless they are proved to the satisfaction of H.M. Customs to have been despatched to this country before February 5, 1941, and are imported before April 5, 1941.

Applications for licences to import compounds of molybdenum, tantalum, tungsten and vanadium, which now become subject to licence for the first time, should be made in duplicate to Iron and Steel Control, Steel House, Tothill Street, London, S.W. 1. Applications for licences to import chemicals already subject to licence should be submitted to the addresses shown in Notice to Importers No. 106, and, in future, they should be made in duplicate.

The Effect of Prolonged Heating at 80°C on Copper Wire

[*Continued from page 104*

in the C.C.C. on long heating at 80° C. is connected with its low silver content. The O.F.H.C. contained more silver than the O.R.C. and was more resistant to softening. It is not, however, suggested that the silver content is the only or even the predominating factor causing the observed differences in behaviour. In the O.F.H.C., for instance, which is deoxidised without the use of deoxidants capable of entering into solid solution in the copper, impurities presumably exist in solid solution in the metallic phase, and therefore exert their full influence in retarding the softening process. On the other hand, a proportion of the more-readily oxidisable impurities in the tough-pitch coppers may be associated with the oxide phase, and thus be prevented from exerting their effect upon the metallic phase. Both the touch-pitch coppers were, in fact, more rapidly softened than the O.F.H.C. Whatever may be the causes of the differences in behaviour, it is interesting to note that they persist under more drastic annealing conditions, as shown in Table V, which gives hardness tests after various treatments on samples of the same O.F.H.C., O.R.C. and C.C.C. coppers in the form of $\frac{3}{16}$ in. diameter rod initially cold-drawn to 50% reduction of area. The figures for the percentage of remaining work-hardness are derived in the same manner as that described for the wires, using the hardness numbers after 1 hour at 600° C. as the fully annealed values. Tables IV and V place the three materials in the same order in respect of annealing behaviour.

The wide recognition of free-cutting aluminium alloy BA 35 has led to its inclusion among the light alloys for which analysis can be standardised. The British Aluminium Co., Ltd., have tabled their procedure with this alloy as an addendum to their well-known volume, "Chemical Analysis of Aluminium and its Alloys." Copies of the addendum may be obtained from the company at Oakley Manor, Belle Vue, Shrewsbury.

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